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Embedded Linux Made Easy

Part 1: Kickoff

+ **Inside Pico C-Super**
AT2313 programming Z80 style



Lossless Load

Keeps energy waste low

+ **High-End MM/MD Preamplifier**
Vinyl & The LPs strike back

+ **Platino Controlled by LabVIEW**
An introduction to LIFA, a LabVIEW interface for Arduino

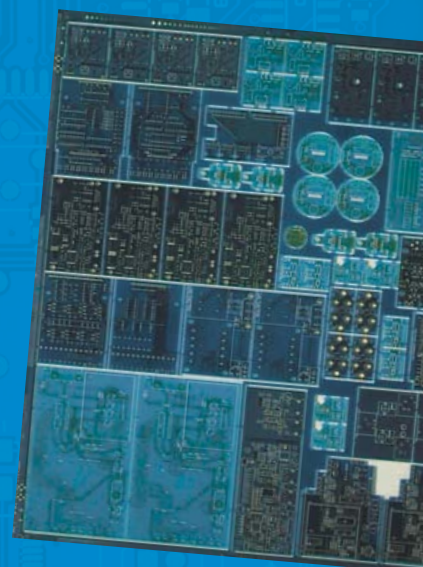


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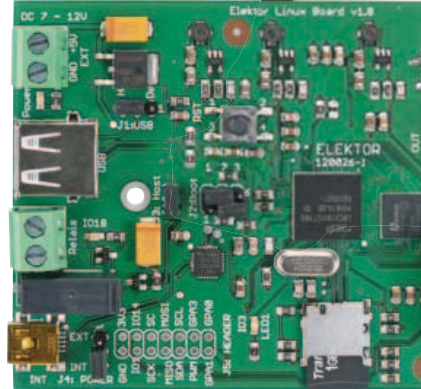
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10^{DEC} Commandments of Electronics

- 00_h. Beware the lightning that lurketh in an undischarged capacitor, lest it cause thee to be bounced upon thy buttocks in a most ungentlemanly manner.
- 01_h. Cause thou the switch that supplies large quantities of juice to be opened and thusly tagged, so thy days may be only on this earthly vale of tears.
- 02_h. Prove to thyself that all circuits that radiateth and upon which thou worketh are grounded, less they lift thee to high frequency potential and cause thee to radiate also.
- 03_h. Take care thou useth the proper method when thou taketh the measure of High Voltage circuits so that thou doth not incinerate both thee and the meter; for verily, thou hast no account number and can easily be replaced, the meter doth have one, and as a consequence, bringeth much woe unto CEO, Accounts & the Supply Department.
- 04_h. Tarry not amongst those who engage in intentional shocks, for they are not long for this world.
- 05_h. Take care thou tampereth not with interlocks and safety devices, for this will incur the wrath of thy Seniors and bringeth the fury of the Safety Officer down about thy head and shoulders.
- 06_h. Work thou not on energised equipment, for if you doth, thy buddies will surely be buying beers for thy widow and consoling her in other ways not generally accepted by thee.
- 07_h. Verily, verily I say unto thee, never service High Voltage equipment alone, for electric cooking is a slothful process and thou might sizzle in thine own fat for hours on end before thy Maker sees fit to end thy misery and drag thee into His fold.
- 08_h. Trifle thou not with radioactive tubes and substances, lest thou commence to glow in the dark like a lightning bug, and thy wife be frustrated nightly and have no further use for thee except thy wage.
- 09_h. Commit thou to memory the works of the Prophets, which are written in the Instruction Books, which giveth the straight dope and which consoleth thee, and thou cannot make mistakes — yeah, well, sometimes, maybe, sorry 'bout that.

(author unknown)



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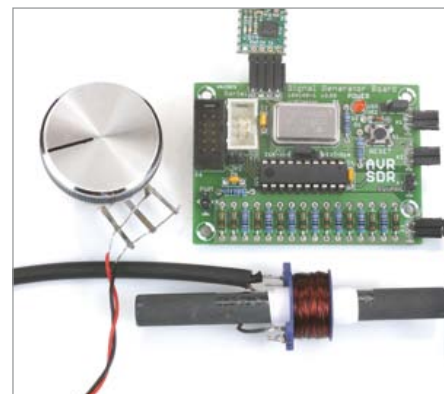
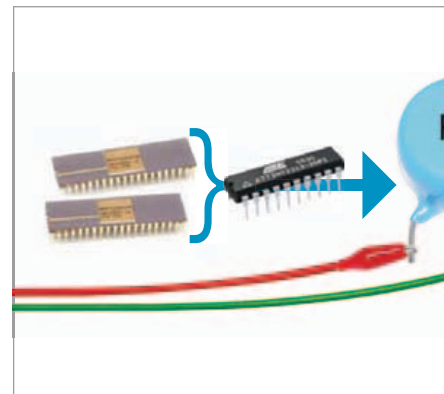
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Today Linux can be found running on all sorts of devices, even coffee machines. Many electronics enthusiasts will be keen to use Linux as the basis of a new microcontroller project, but the apparent complexity of the operating system and the high price of development boards has been a hurdle. Elektor solves both these problems, with a beginners' course accompanied by a compact and inexpensive circuit board.



28 Preamplifier 2012 (2)

High-end turntables are available at extragalactic prices but none of this makes any sense if you do not have a preamplifier to match your MC or MD cartridge optimally and that's exactly what the present design does — rather successfully. Part 2 of our preamplifier 2012: the Moving-Coil / Moving-Magnet (MC / MM) board.



40 Inside Pico C-Super

The Pico C-Super is an extended version of the original idea with several extra functions crammed into the same extremely simple and low cost hardware through the use of software. In this afterburner article we delve into the software that makes the instrument tick, particularly the Plus version.



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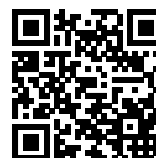
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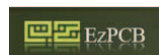
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to reserve your own space for the next edition of our members' magazine

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Smart Reset™ Chips cure frustration

STMicroelectronics announces its new generation of Smart Reset™ chips. Pioneered by ST who has already supplied tens of millions to major consumer-electronics brands, smart-reset Integrated Circuits provide a safe, convenient and intuitive means of resetting 'frozen' gadgets, such as mobile phones, media players, and other portable consumer devices.



Traditionally, when electronic devices freeze or lock up, users would either try to remove the battery, which is not always convenient, or find an appropriate tool to press the dedicated reset button placed in a hole that is often difficult to access. Smart resets extend the functional capability of the existing buttons so that users can simply re-set their frozen device with a long push of one or two buttons simultaneously, depending on the device configuration. With the increasing popularity of touch-screen devices, smart resets remove the need for extra buttons, saving space and cost for the equipment manufacturers, and significantly increasing convenience for the user.

Effective prevention of accidental resets is secured with the STM6524, ST's newest dual-assert Smart Reset IC. Its two inputs connect to a selected pair of buttons on an electronic gadget. When these buttons are held down simultaneously for a manufacturer-specified time, the IC sends a reset signal to the main processor. The combination of two inputs and programmable delay time effectively prevents accidental resets. ST is also introducing a new single-assert Smart Reset IC, the STM6519, which targets single-button electronic devices like tablets and e-readers, with a similar programmable delay reset.

The new generation of ST's Smart Reset IC offers several improvements over existing solutions: in addition to a smaller package size, the new devices implement a customizable extended input delay time, from 0.5

to 10 seconds, which increases flexibility and enables manufacturers to distinguish their products through specific user-interface settings. The new smart resets also integrate a dedicated test mode, which improves device testability and slashes test costs.

<http://www.st.com/internet/analog/product/252433.jsp>
(120209-8)

New 50 W, 4-channel AC-DC LED driver with standard dimming

Phihong USA has developed a new series of multi-channel drivers for indoor and outdoor lighting applications. Designated the PDA050W-450G, the driver is equipped with four outputs of 450mA and offers a standard 0-10V dimming capability.

"The lighting industry is making a decided move from fluorescent and compact fluorescent bulbs to much more cost-effective and environmentally friendly LED diodes and drivers for longer lasting energy savings," said Keith Hopwood, Vice President of Marketing for Phihong USA. "Phihong is committed to staying ahead of the curve by introducing a line-up of cost-competitive external AC-DC drivers to retrofit existing lighting installations as well as for OEMs and their rapidly growing demand for high



quality lighting power."

The power supply is equipped with four constant current outputs of 450 mA at a nominal output voltage of 24.5 VDC. With an AC input range of 90 VAC to 304 VAC the driver can be operated at the standard North American mains voltages of 120 VAC or 277 VAC for residential, commercial and industrial applications. The driver bears safety approval from UL, meeting UL8750, and has outputs that are Class 2 per UL1310 that are appropriate for linear fluorescent

replacement installations.

The PDA050W is water-resistant and fully potted with ingress protection ratings of 65 and may operate in a temperature range of 0°C to 50°C. The highly efficient and reliable driver has minimum average efficiency ratings from 82% at 120 VAC input to over 84% at 277 VAC input and has a calculated lifetime of 50K hours at maximum load and ambient 50°C.

The LED driver comes fully equipped with input over-current protection, short-circuit protection, output over-voltage protection and open-circuit protection and has a minimum power factor correction greater than 0.9. Phihong also offers a 5-year warranty on selected LED drivers including the PDA050W.

Designed in a typical ballast shape and size for ease of retrofit implementation in office lighting fixtures, the series measures 242 x 43.5 x 30.5 mm and weighs 675 grams.

www.phihong.com/LED
(120209-9)

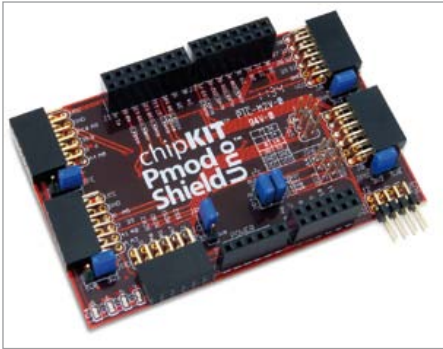
New Digilent Pmod Enables Arduino® / Digilent Interface

Digilent® has announced expanded capabilities for the chipKIT™ development platform for the Arduino® community. The company has released another shield, the chipKIT Pmod Shield-Uno™. This shield provides circuitry and connectors to enable Digilent peripheral modules (Pmods™) to be used with the chipKIT Uno32.

"The Pmod Shield-Uno bridges the connection between chipKIT and Digilent Pmods. Professionals, hobbyists, and academics can now build both simple and advanced chipKIT-based projects with over 50 different Digilent Pmods," said Clint Cole, president of Digilent.

Digilent Pmods include sensors, WiFi and Bluetooth interfaces, rotary encoders, LED displays, keypads, joy sticks, data acquisition & conversion, connectors, external memory, and much more.

The Pmod Shield-Uno has five 2x6 Pmod connectors. It also provides access to the I/O connectors on the Uno32 as well as connecting to the I2C bus supported by the Uno32. When used together, the Pmod Shield-Uno and the Uno32 let both Arduino-style shields and Digilent Pmods



use all the features of the Microchip PIC-32MX320F128H microcontroller on the Uno32.

Digilent's chipKIT development platform is a 32-bit Arduino-style solution that enables hobbyists and academics to easily and inexpensively integrate electronics into their projects, even if they do not have an engineering background. The platform consists of two PIC32-based development boards and open-source software that is compatible with the Arduino programming language and development environment. Digilent's chipKIT hardware is compatible with existing 3.3 V Arduino shields and applications, and can be developed using a modified version of the Arduino IDE and existing Arduino resources, such as code examples, libraries, references and tutorials.

The chipKIT Pmod Shield-Uno costs only \$26.95.

www.digilentinc.com
(120332-II)

High-speed digital data logger with extended recording capacity and data filtering capability

Saelig Company, Inc. has introduced LOG Storm, a new high-speed digital data logger for troubleshooting digital system buses. LOG Storm contains an 8-MSample memory buffer, enabling large bursts of data up to 20bits at 100 MHz to be sampled. A USB connection is used to stream collected data to the PC, enabling Gigabytes of data storage. LOG Storm's most useful feature is its data filtering capability, efficiently storing only relevant data.

Design engineers often use a logic analyzer for digital system debug. But they frequently report that this type of equipment

150 farads at 14 volts

Australia-based CAP-XX, a developer of thin, prismatic supercapacitors, has developed a supercapacitor module which supplies the cranking current to start the engine in Stop-Start vehicles (also known as start-stop, idle-stop, or micro-hybrid vehicles), reducing wear on the battery and eliminating the need for larger, more expensive ones.

CAP-XX's prototype Stop-Start supercapacitor module supports the battery by supplying the peak current (up to 300 A) needed for each engine start. Containing six of the company's thin supercapacitors, the module is about the size of six DVD cases so it integrates easily into a vehicle's floorpan, engine bay, or other tight spots. With 150 F at 14 V, and an ESR of just 4.5 milliohms, the module offers the best power density available today, and the energy necessary to support frequent start cycles in all conditions. It

includes the control electronics to manage Stop-Start functions, balance the voltage across each supercapacitor cell, and limit the battery current during each restart.

With the module installed, the vehicle battery only needs to support continuous power functions such as air conditioning, navigation and lights. The battery also charges the supercapacitors for their first start, but once driving, the alternator keeps them charged. Additionally, the module will start the engine in low temperatures where a battery would falter, and can store energy in vehicles with regenerative braking systems.

In testing under the New European Drive Cycle (NEDC) standard, the supercapacitor module completed more than 110,000 Stop-Start cycles at room temperature, successfully maintaining the battery voltage above 11.8 volts. CAP-XX identifies the battery as having failed when voltage falls below 10 volts because, based on input from a leading European automaker, batteries at this state of charge can no longer operate vehicle electrical systems reliably. Comparative tests of a battery-only system, also at room temperature, saw the battery fail after only 44,000 cycles.

CAP-XX will partner with automobile parts suppliers to manufacture the modules, designing and prototyping the modules to suit their requirements. CAP-XX estimates its module would cost approximately US\$60 in mass production, and is already in negotiations with a Chinese automotive component company to commercialize the technology in China.

www.cap-xx.com (120332-I)



is unhelpful when problems result from a long sequence of combined software and hardware events. Logic analyzers cannot record sufficient depths of relevant data history to be useful. In contrast, LOG Storm is a dedicated hardware/software combination that can collect high-speed digital bus activity for periods of hours or even days, and extract specific functional events of interest. LOG Storm offers compact,



easy-to-deploy data logging with huge storage capability, a high sampling rate and rich data storage qualification capabilities. Examples of use include: SPI message monitoring of specific slave select lines; continuous, filtered data packet header evaluation; long-term bus monitoring; in-lab development; on-site, after-installation servicing for chip-to-chip communication emulation, IP evaluation, etc.

LOG Storm will be introduced at the Design-West Conference and Exhibition in San Jose on March 27-29, 2012.

Made in Europe by Byte Paradigm, a leading embedded test equipment manufacturer, LOG Storm will be available in March 2012 at \$1599.

www.saelig.com
(120332-IV)

Atlantic Technology: WA-5030 wireless with power Amp

Atlantic Technology has introduced a 30-watt amplified wireless audio system which can drive a pair of loudspeakers at ranges of up to 300 feet from the transmitter.



The Atlantic Technology WA-5030 Wireless Transmitter/Amplifier System combines a brand new WA-5030-r zone amplifier and wireless receiver with the company's proven three-zone WA-50-t wireless transmitter. The WA-50-t transmitter can be sourced from any RCA analog audio line outputs or to a Mac or PC via a built-in USB connection. It broadcasts lossless, uncompressed CD-quality digital audio with a 48 kHz sampling rate over on the 2.4 GHz radio band. The wireless technology is highly robust

with no data drop issues and essentially no time delay over distances of 150 to 300 feet depending on intervening structures. A three-position zone switch on both the transmitter and receiver allow up-to three separate WA-5030 systems to be used in close proximity to each other.

The system's WA-5030-r receiver/amplifier contains a matching 2.4 GHz RF section, digital-to-analog converter, and a high-quality 30-watts per channel stereo

power amplifier. The receiver is suitable for driving most compact bookshelf or in-wall/ceiling 8-ohm speakers to high sound levels with low distortion. The WA-5030-r also comes with an infrared wireless remote control, to allow users adjust volume and to mute the system. WA-5030-r can also be programmed to drive speakers in the bi-amp mode or to drive speakers in a commercial or distributed audio system.

"Our WA-50 wireless audio system has

High accuracy programmable DC Power supply generation

Magna-Power Electronics has released its next generation product line featuring major performance upgrades. The new generation, spanning every product model from 2 kW to 2000 kW+, addresses a wide-range of new demanding application requirements. Key new features introduced are:

- **High Accuracy Programming and Monitoring:** Enhancements to the product controls and calibration procedures enabled an over five-fold improvement in accuracy. Accuracy specifications are now $\pm 0.075\%$ of full-scale voltage/current programming and $\pm 0.2\%$ of full-scale voltage/current monitoring. Higher accuracy enables measurements to be taken directly from Magna-Power Electronics power supplies, eliminating the need for external power meters and lowering overall system costs and complexity. All power supplies still maintain ease of front panel calibration.
- **Electronic Output Bleeder Stage:** Standard output bleeder resistance was replaced with near constant power electronic loading. The new output stage enables faster fall times, and improved performance under light loading without affecting overall efficiency. (XR/TS/MS Series only)
- **Integrated EMI Filter:** Formerly an option, integrated EMI filters now come standard on the entire product line, enabling improved EMI/EMC performance. All products ship with CE conformity.



In addition, new low voltage high current models along with a 2000 Vdc+ High Output Isolation Option (+ISO) were also introduced on the TS Series and MS Series. All products series numbers are incremented to reflect the new generation: XR Series III (2 kW to 8 kW), TS Series IV (5 kW to 45 kW), MS Series IV (30 kW to 75 kW), and MT Series VI (100 kW to 2000 kW+).

The new generation is now available and the built-to-order lead-times are as short as 2 weeks, consistent with Magna-Power Electronics newly reduced delivery schedules.

www.magna-power.com (120332-VI)

been very popular with our dealers and we've even had a few great reviews from audiophile magazines," said Steve Feinstein, Director of Marketing and Product Design, Atlantic Technology. "However, several dealers immediately suggested that we 'combine the receiver with a small integrated amplifier.' We always think it is a good idea to listen to our dealers."

The WA-5030 wireless audio system is easy to set up and use. Up to three WA-50-t transmitters and three receivers per transmitter can be used in a system. Simply connect the WA-50-t transmitter to the desired RCA audio outputs or USB source, and the WA-5030-r receiver to a loudspeaker system. Both the transmitter and receiver have a three-position switch that assigns each pairing to either Zone 1, Zone 2, or Zone 3.

www.atlanticttechnology.com
(120332-V)

New planar transformer series

Würth Electronics Midcom Inc., a world leader in the design and manufacture of custom magnetics, introduces the newly developed planar transformer product series.

The series is optimized for frequencies ranging from 200 kHz to 700 kHz, with 500 VDC isolation and 250 watts power handling capabilities. Developed to be fully customizable to individual customer needs, the planar SMD

transformers comes in multiple turns ratio options with optional Aux winding for maximum flexibility. The parts have a low-profile height of 10mm and an operating temperature range of -40 °C to +125 °C.

The patent-pending design offers a multitude of advantages compared to traditional bobbin-wound products including reduced size and weight, high efficiency, low leakage, consistent parasitics and excellent thermal characteristics. The innovative use of pre-formed flatwires yields significant cost reductions compared to existing stacked layer and multilayer PCB designs.



www.we-online.com/planar (120332-III)

LEDagon reference system accelerates solid-state lighting designs

Arrow Electronics, Cree, Haeusermann and Kathrein Austria have announced LEDagon, a unique LED lighting solution. The LEDagon LED reference lighting system showcases a variety of solid-state lighting technologies including thermal management solutions, innovative printed circuit boards, sensors and other electronic components in a straightforward manner that is easy to understand.

LEDagon provides companies with an opportunity to implement product ideas quickly and economically with market-leading suppliers. Arrow, Cree, Haeusermann and Kathrein Austria have formed a partnership that offers a complete spectrum of technologies and services to meet all needs, ranging from design support,

through the integration of state-of-the-art technologies, to assembly and component procurement. LEDagon is based on HSMtec, a copper/FR4 printed circuit board technology developed by Haeusermann. HSMtec enables optimized thermal management for High-Power LEDs and arrays, high current capabilities and multidimensional PCB structures for individual lighting- and product-design. LEDagon also adds intelligent control electronics featuring a microcontroller and Xlamp high-performance LEDs from Cree that enable new application areas for LED lighting. Parameters, including position, direction, brightness and temperature, can all be managed via the sensor-based controller. Capacitive buttons and sliders on the housing can be used for setting different operating modes. A seven-segment display shows the current operating mode. Software updates can be downloaded via



a mini USB 2.0 interface. A Windows host application is integrated that allows the user to control the system remotely, analyse results or install firmware updates. Energy supply is via a standard DC power supply.

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(120332-IX)

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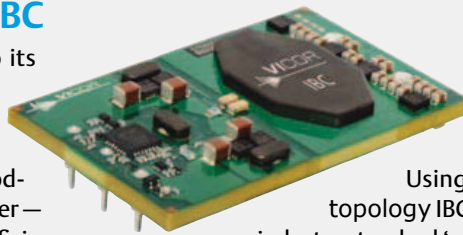
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850W, 80A Quarter Brick IBC

Vicor announces the newest addition to its IBC050 product line of high performance, wide input range VI BRICK™ intermediate bus converters (IBCs). The new IB050Q096T80N1-00 quarter-brick IBC module can provide up to 850 W of output power — far exceeding the power capability and efficiency of competitive bus converters — making it ideally suited for demanding applications spanning enterprise, optical access and storage networks.

Available as a drop-in upgrade for industry standard 5:1 fixed ratio converters, the new IBC module operates from a 36 V to 60 V input voltage range, with 2,250 Vdc isolation from input to output while achieving 98% peak efficiency. Rated at up to 80 Amps, 850 W from 55 to 60 Vin and 550 W from 36 Vin, the 58.4 x 36.8 x 10.5 mm quarter-brick module allows designers to conserve valuable board space and achieve full load operation at 50 °C with 400 LFM airflow.

The IB050Q096T80N1-00 IBC module yields maximum usable power in thermally constrained systems. Its open frame construction facilitates airflow above and below the module to minimize temperature rise of downstream components. Using an



industry standard form factor and pinout, the new IBC module equips customers with greater power capability freeing up valuable board space.

Using Vicor's Sine Amplitude Converter™ topology IBC050 series modules are pin-compatible with industry standard 'square wave' bus converters, which are fundamentally limited by switching losses to low operating frequencies, low power densities and low bandwidth. Operating at 1 MHz, the IB050Q096T80N1-00 IBC module cuts transient response time by a factor of 10 and eliminates the need for bulk capacitors across the intermediate bus.

Designers can take advantage of Vicor's new IBC Power Simulation tool, an industry-first online simulation capability, to interactively model the electrical and thermal performance of the IB050Q096T80N1-00 IBC module in application-specific operating conditions and thermal environments. Available to users via Vicor's PowerBench™ online design centre, Vicor's IBC power simulation tool enables designers to quickly and easily select, simulate and optimize IBC performance under a variety of system thermal and electrical conditions.

www.vicorpower.com (120332-VIII)

Vinco platforms gets Ethernet-to-USB, MP3 audio codec & real-time clock functionality

Furthering market progression of the widely praised Vinco platform, USB solutions specialist Future Technology Devices International Limited (FTDI) has announced the introduction of its new multi-function application board (shield). By combining the Vinco development platform, with targeted application support, such as MP3 audio codec, Ethernet-to-USB bridge and real-time clock (RTC), engineers can jump-start their development.

This latest shield offering incorporates a VLSI VS1053b codec for the decoding of various audio files (Ogg Vorbis, MP3, AAC, WMA, FLAC, WAV and MIDI), Ethernet connectivity, plus an RTC feature using NXP Semiconductors' PCF32123 timing device.

Designed to connect directly to the Vinco development/prototyping board, the shield enables the Vinco's Vinculum-II (VNC2) dual-channel USB host/device controller

IC to access an Ethernet port via a Wiznet W5100 chipset. The W5100 converts Ethernet data into SPI data (and vice versa). The SPI port is a slave to the VNC2 SPI master. A set of 4 LED indicators on the shield show the nature of the Ethernet traffic, so that engineers can determine whether the



shield is receiving data, transmitting data, is in full duplex, or is experiencing data collisions. The shield also has a hardwired TCP/IP stack that permits 10Mbit/s or 100Mbit/s data transfer over the Ethernet link, so the system it is incorporated into can be networked with other systems.

An MP3 audio file player gives access to MP3 files from the USB drive accessed through the Vinco motherboard. A 3.5 mm audio socket provides the interface for connecting headphones or an amplifier to the audio codec output.

The shield comes in a 55.4 mm x 68.6 mm format. A 3.3 V supply is required to power the PCB. This is generated through an onboard regulator supplied with 5 V from the Vinco board. An additional 1.8 V supply is needed for the VS1053b audio codec's operation, which can also be generated from an on-board regulator.

FTDI has free software libraries and Ethernet, SPI Master and GPIO drivers to support the new Vinco shield - furnishing engineers with all the building blocks they need to implement Ethernet, MP3 and RTC applications. An Integrated Development Environment (IDE), that includes a code editor, 'C' compiler, assembler and debugger, can be downloaded for free from the company's website.

The FTDI Vinco multi-function Ethernet, RTC, MP3 shield is available at a cost of \$59.50 for single units.

www.ftdichip.com
(120332-XI)



The RL78 Green Energy Challenge

Now's your chance to develop a unique and energy-efficient project application that could change the perception of low-power design forever! Get your green on and join the Renesas RL78 Green Energy Challenge today for a chance to win your share of a \$17,500 cash grand prize!

Plus, follow Renesas on Twitter and Facebook for your chance to win additional prizes from official contest partners. **Every Monday, Renesas will post a new challenge question.** Answer correctly and you'll be entered into a drawing to win free development tools, Pmods, Wi-Fi modules, embedded systems books, cash prizes, and more! Challenge winners will be notified and announced weekly.

**\$20,000
in cash
prizes...**

**...and
additional
weekly drawings**



In association with *Elektor* and *Circuit Cellar*

Official Contest Partners: Analog Devices, Inc., CMX Systems, Inc., Exosite, GainSpan Corporation, Micrium, NDK Crystals (Nihon Dempa Kogyo Co., Ltd.), Okaya Electric Industries Co. Ltd., and Total Phase, Inc. Participation in Weekly Challenges and receipt of partner prizes is not a factor in selecting winners for the Grand Cash Prize from Renesas. See website for complete rules and details. Void where prohibited by law.

For complete details, visit

www.circuitcellar.com/RenesasRL78Challenge



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Embedded World 2012 10 years

By Clemens Valens & Antoine Authier (Elektor UK/International)

This year the Embedded World electronics show in Nürnberg, Germany, celebrated its tenth anniversary. Bigger than ever, the show has moved into larger halls where more than 20,000 visitors rallied to see the products on offer. Elektor was there too and talked to several exhibitors to learn what the (near) future will bring.



The Embedded World (EW) show is mainly about microcontrollers; analogue purists & Jan Buiting ☺ should refrain from visiting¹, and all the companies that rank or aspire to rank in this business were there. Since this was not our first visit to this show, we have developed certain habits including going straight to the STMicroelectronics booth to pick up a free board. This year a voucher was needed to get a cool 32-bit ARM Cortex-M4 STM32F4-Discovery board. Where last year the Cortex-M4 was just being introduced, now it was being proposed by several manufacturers. Targeted at signal processing and audio applications, this powerful MCU features DSP extensions and a floating point unit and will probably make a lot of noise in the years to come. NXP too is very active here and component distributor Future Electronics too showed us a Cortex-M4 based audio streaming board they developed in-house using a Freescale CPU.

On the subject of processing power, Toradex, a Swiss manufacturer of small computer boards, had organised a special show offer: donate 20 € to the Swiss Red Cross and get a Colibri T20 computer module plus carrier board in return. This combination, sporting a dual-core NVIDIA Tegra 2 ARM Cortex A9 processor and supported by Windows CE and Linux, can boot in a staggering 500 ms.

Of course we got one of those hot-rods and tried it in our labs where it was found to boot faster than the LCD computer monitor it was connected to. The thousand boards on offer were gone in less than two days, according to a Toradex spokesman.

You may have noticed that ARM came up already a few times in this article. Well, to be honest, it was ARM all over the place. Of course the people at the ARM booth were pretty satisfied with this and they bragged happily about their success. It seems that only Microchip with their MIPS-based PIC32 family tries to resist ARM, but they are probably in for a rather hard time, especially when you know that ARM's next goal is no less than the extermination of the 8-bit microcontroller, Microchip's best-selling product (over 1 billion devices sold in 2011). The Cortex-M0 is ARM's not-so-secret weapon which is being sold by their licensees (NXP even proposes DIP packages!) at sub-dollar prices, cheaper than most 8-bit devices.

On the 8-bit front Microchip launched the PIC12F752 MCU family for LED lighting and battery charging applications. These devices contain an integrated complementary output generator (COG) for providing non-overlapping, complementary waveforms to inputs such as comparators and PWM peripherals.

One of Microchip's other novelties at the show was the announcement of small (down to 5 x 5 mm) PIC32 MX1 and MX2 devices in 28 to 44-pin packages. Featuring dedicated audio and capacitive-sensing peripherals and USB On-the-Go (OTG) capabilities, they are targeted at mobile audio accessories.

Microchip also does 16-bit devices as illustrated by the new PIC24F 'KL' family. These are of the eXtreme Low Power (XLP) variety, featuring typical sleep currents of 30 nA at 25 °C, and typical run currents of 150 µA/MHz at 1.8 V. This may seem very little, but Texas Instruments showed that it is possible to do better. Indeed, for



Photo 1. The audio streaming board by Future Electronics is based on a Freescale Kinetis K60 with ARM Cortex-M4 core.

of showcasing embedded electronics



their 'Wolverine' family of ultra-low-power MSP430 devices TI drily announces 360 nA real-time clock (read stand-by, not sleep) mode, and less than 100 $\mu\text{A}/\text{MHz}$ active power consumption. TI claims it to be the world's lowest-power microcontroller platform. In case you wonder about the name Wolverine, it was chosen in honour of the character from the X-Men comics because of its slashing power (pun intended).

At the Atmel booth we had a look at software: version 6 of their Studio IDE. This used to be called AVR Studio, but dropping the AVR bit was exactly what was new about it. This does not mean that AVR is no longer supported; it means that it now also supports Atmel's (here-they-are-again) ARM Cortex-M based MCUs (not ARM7). Atmel Studio 6 now supports roughly 300 of the company's MCUs and comes with Atmel Software Framework (ASF, formerly called AVR Software Framework), a large library of source code that includes about 1,000 project examples.

More software and more ARM based MCUs were on display at the Toshiba booth. Toshiba has sort of embraced the "if you can't beat them, join them" philosophy and are now proposing ARM-based devices too. They managed to introduce a special twist however by creating an MCU for motor control that has an integrated DSO. No, there is nothing wrong with your eyes, this chip does include its own digital storage oscilloscope. Supported by a very nice software tool you can quickly create a brushless motor driver and have a look at the signals too. The motor controller is all in hardware and doesn't eat into processing power. Simply counting revolutions it comes pretty close to a stepper motor controller. You are definitely going to read more about this MCU in Elektor.

Cypress, the Programmable System-on-Chip (PSoC) company, showed us their new stuff. Their design software now includes a nice component browser to which they will steadily add new modules. Also a digital filter designer tool is now available that lets you



Photo 2. Toshiba has integrated a digital storage oscilloscope (μDSO) in its Cortex-M3 based MCU for motor control applications. Is this the start of a new trend?

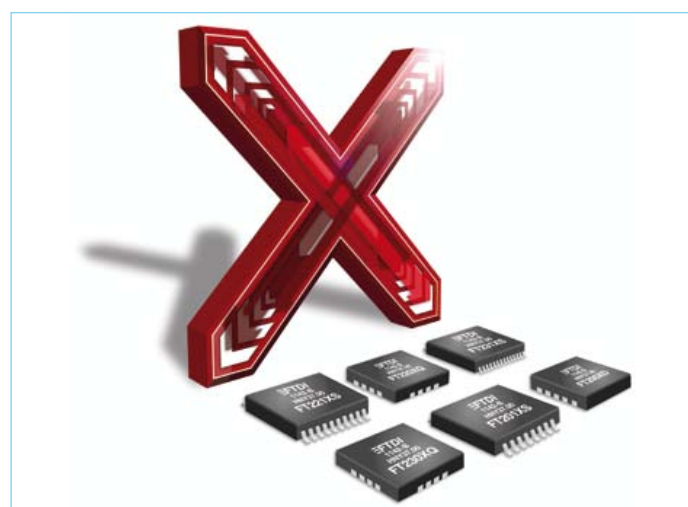


Photo 3. After xXx, X is now hot too. Here is FTDI's new X-family of USB bridges.

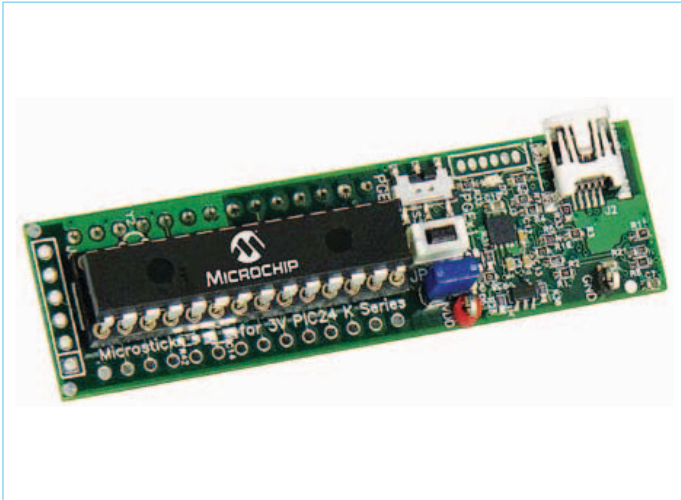


Photo 4. Microchip's Microstick for PIC24KL eXtreme Low Power MCU family is of course supported by MPLAB X.

easily configure the hardware filter blocks of the chip. If you have ever tried a development or evaluation board, you will know that often they come with, among others, a kick-start version of an IAR compiler. Programming and debugging of such boards usually requires a special pod that in some cases can be on-board. Most of the time these pods are licensed in some way or another by Segger, but the people at IAR have now developed their own and they proudly presented the brand-new bright yellow I-jet. This pod can be used with most ARM processors.

From pods to FTDI is only a small step as both rely heavily on USB. At Elektor we use a lot of FTDI USB serial converter chips in our projects, so we were interested to learn about the new X-Chip series made up of 13 devices. These devices offer full speed USB 2.0 bridging to UART, SPI/FT1248, I²C and FIFO interfaces, complementing the company's existing R-Chip, and Hi-Speed products.

At the show FTDI staff gave away free USB to I²C breakout boards (UMFT201XB-01) the size of a USB stick. To make such a board work you will have to install drivers. At the Elektor Labs we found that you need at least version 2.08.23. This means that Windows 2000 and older are not supported. Linux drivers do not seem to be available at the time of writing although the datasheet says otherwise, Mac OS X may work and Android should work too.

Lantronix and Digi are competitors in a niche market: Linux-based web servers the size of and including an RJ45 connector. This year Lantronix set a new record by making the module even smaller, partly because they removed the RJ45 connector. The xPico is a complete device server application with full IP stack and web server measuring only 24 x 16.5 mm. iPad/iPod users may be interested



Photo 5. Named after X-Men character Wolverine, the new MSP430 from Texas Instruments features less than 100 μ A/MHz active power consumption.

in Lantronix's xPrintServer that allows you to print to any printer in your sub network, Android users will get their version soon, it is currently in the beta testing stage.

Digi, whom you may know from the XBee wireless modules, had other news. Besides the new XBee-PRO 868 module supporting RF line-of-sight distances up to 80 km, they told us about their evolving cloud services. One very interesting item that came up was the availability of iDigiConnector, a free portable stack for microcontrollers to connect to the iDigi cloud. Ooh, do we see a project coming?

Our last stop almost at closing time of the show was at the WIZnet booth. This Korean manufacturer specialising in hardwired Internet chips and modules now has an official European subsidiary. Here we picked up some interesting product samples you will soon discover in Elektor. Thanks a lot, Joachim!

That concludes our report of three days running around, talking to companies and watching demonstrations. Of course there was much, much more on display in Nürnberg but unfortunately (or luckily?) we do not have the space to write about everything we saw. Maybe next year.

(120297)

Note

1. Jan will visit Design West 2012 (San Jose, California) though, where microcontrollers and sunshine are valued roughly equally.



The RL78 Green Energy Challenge has begun

Are you ready to shape the future we live in?

Green Energy ideas are rapidly changing our future, so what's your idea? Here's your opportunity to step into the light, present your Green Energy design to the world, and help create a future that's bright, clean, and healthy.

By Rob Dautel (USA)

Green Energy. It's a phrase that's become so commonplace in the past few years that we now hear it every day of our lives. But what is it? Ask a group of people and you're sure to get a range of different answers. Some would say it's improving and using our current energy systems and supplies better and more efficiently. Others might say it's concentrating on building out technologies for alternate energy such as wind, solar, and geothermal. Perhaps it's completely new ways of thinking such as energy harvesting and extreme low power means like RF gathering, heat scavenging, and piezo mechanical generation. Even others may say it's creating intelligent control systems, monitoring, data gathering, and processing to better utilize energy and resources whatever the source technology may be.

The encompassing term 'Green Energy' is not limited to electrical energy, but rather has become a blanket term adopted by a wide breath of industries covering a host of topics from natural resources like water, air, minerals, and petroleum, to building structures and best practices, materials reuse, and working smarter and more efficiently both for ourselves and our surroundings.

In only a few short years, the Green Energy idea has taken the world by storm and whatever the definition, one thing is clear; Green Energy is about making the world a better place to live, work, and play in.

So what is Green Energy to you? That's what the RL78 Green Energy Challenge is all about. We want to see your ideas, your designs, and your future of the Green Energy revolution. Perhaps it's a remote device monitoring pollution. Maybe it's a box collecting data on home power usage or an energy harvesting biometric design. It could be a low power controller scavenging heat from an oven or furnace, a meter reading biomass parameters, or a braking system for a wind turbine. It's up to you.

Renesas and our contest partners want to see what your version of the Green Energy future looks like so we've giving away more than \$20,000 in prizes in the RL78 Green Energy Challenge.

We're looking for designs that take us to the next level, that define the essence of Green Energy, and inspire others to stand up and do the same. We're not just host-

ing a design contest; we're beginning a grass roots movement that begins with you. As embedded systems become more and more connected to each other and to cloud resources, we're enabling new ways to gather, process, and react to data and the environment around us. This new level of connected processing provides a never before seen ability to interact with and manage resources and the world in which we live.

The RL78 Green Energy Challenge will focus on designs using the Renesas RL78 family of microcontrollers which combines advanced low power technology, outstanding performance, and the broadest line-up in its class for the most demanding 8- and 16-bit embedded applications. These MCUs incorporate key features of the well-established R8C and 78K0R families from Renesas Electronics, giving designers an excellent upgrade path for next-generation designs. The platform concept of the RL78 family provides great flexibility while 41 DMIPS at 32 MHz and 66 μ A/MHz provide for high efficiency and ultra low power operation.

To make your RL78 Green Energy Challenge design a reality we're giving away nearly 1,000 RL78G13 Renesas Demonstration Kits or RDKs. We've worked hard to include a range of features into these kits to make designing with the RL78 fun and easy. The kit includes an onboard debugger, 3-axis accelerometer, temperature sensor, LCD display, isolated triac, a light sensor, FET circuit, IR transmitter and receiver, serial EEPROM, microphone input, audio output, SD card slot, Pmod connector, and much more, see Elektor April 2012. To top off the hardware, we've partnered with IAR to provide their Embedded Workbench Kickstart Edition for RL78 and during the duration of the challenge, they will provide full licenses of their Embedded Workbench to contestants. We've also partnered with other great companies such as Micrium, CMX Systems, SEGGER, Total Phase, Exosite, and Okaya to provide a host of software and code examples to start your design off fast.

So, if you've already signed up for the RL78 Green Energy Challenge, we welcome you and thank you for being part of something we truly believe can help shape the future and if you have not signed up yet, what are you waiting for? Do it today and show us what you've got and what Green Energy means to you!

(120288)

Sign up at www.circuitcellar.com/RenesasRL78Challenge



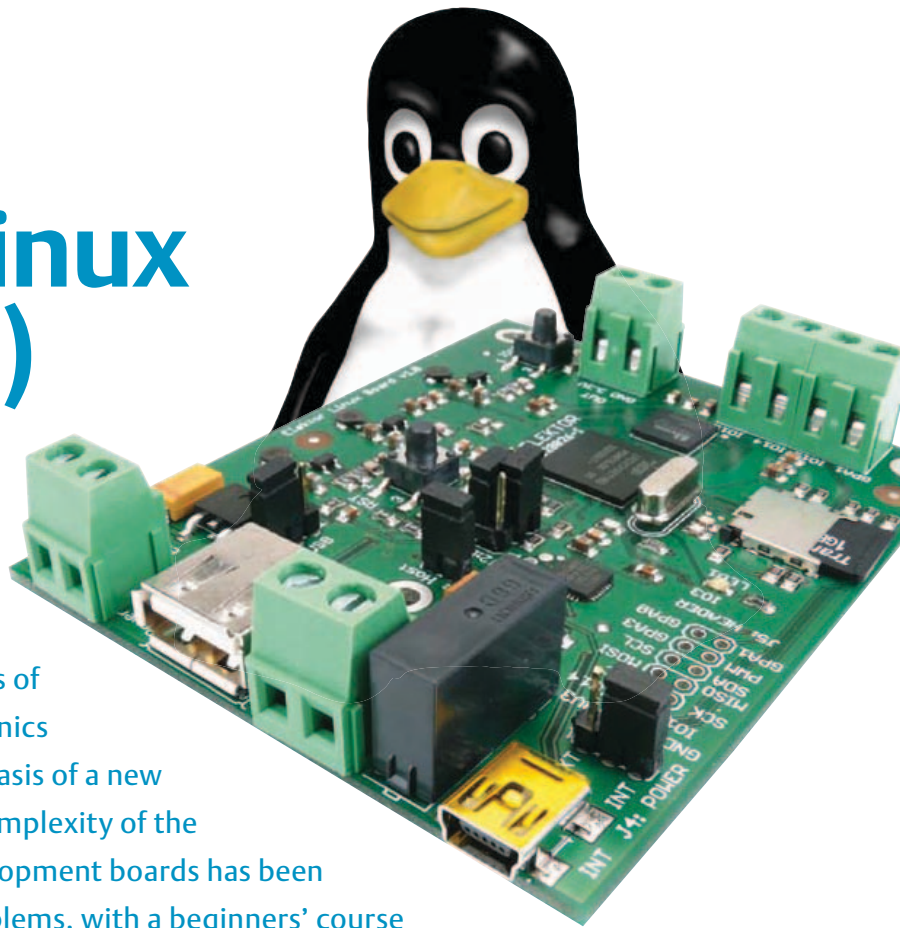
Rob Dautel, Sr. Manager of Ecosystems at Renesas Electronics America, has more than 24 years experience in hardware, software, and ASIC design. He is an expert in digital audio, industrial control, and development tools. He 'speaks' 22 different programming languages.

Embedded Linux Made Easy (1)

Part 1: Kickoff

By Benedikt Sauter (Germany) [1]

Today Linux can be found running on all sorts of devices, even coffee machines. Many electronics enthusiasts will be keen to use Linux as the basis of a new microcontroller project, but the apparent complexity of the operating system and the high price of development boards has been a hurdle. Here Elektor solves both these problems, with a beginners' course accompanied by a compact and inexpensive circuit board.



There are many introductory courses available for eight-bit microcontrollers, but comparatively little literature and comparatively few websites address the needs of beginners in embedded Linux. Many descriptions assume too much prior knowledge or descend too quickly into cryptic source code, specialist topics or other unwanted detail. However, Linux is at its heart just a classical, well-structured and very modular piece of firmware, and, despite its apparent complexity, it is possible to understand it in terms of ordinary microcontroller concepts. What do we need to take our first steps in this world? In the early days of computing and microprocessors it was relatively easy for an interested user to understand the hardware, the operating system, the applications, drivers and all other parts of his machine. The main reason for this is that there was not the same enormous choice of components as we enjoy today, and so it was easier to focus one's efforts on the components and tools that were available. Normally people built and operated their hardware in their own individual way, and hence it was usually down to the individual to fix his own bugs and faults. This in turn demanded an in-depth knowledge of how the system worked.

This is the approach we will take to understanding Linux in this series of articles. Our hardware will be a compact board that

includes everything necessary for a modern embedded project (**Figure 1**): a USB interface, an SD card connection and various other expansion options. It is also easy to hook the board up to an Ethernet network, as we shall see later in the series. The Elektor Linux board is based on the 'Gnublin' open source project, which was developed at the Augsburg University of Applied Sciences for teaching purposes [2].

There are no specialist components on the Linux board. The printed circuit board has two layers and is available from Elektor ready populated (see **Figure 2**). The second part of this series will look more closely at the circuit diagram, but we also show it here (**Figure 3**) for the sake of completeness. The hardware is available under the 'freedomdefined.org/OSHW' licence, which means that the CAD files are also available [3]. Needless to say, the software for this project is also entirely open source, and is as always available for download from the Elektor website [3].

Step by step

Figure 4 shows an outline of the roadmap for this course. The first thing for Linux beginners to understand is where the most important applications and software components originate from. These components form the basis of our Linux system, just as they do of any PC-based Linux system. We

will also learn how the hardware is constructed and how it operates. And then we will see how to install a suitable Linux development environment on a PC to compile our own source code: when installing Linux on a microcontroller it is much easier if the host PC development environment is also running Linux (for compatibility of directory pathnames if nothing else). Windows users have the option of installing Linux in a virtual machine.

By the end of the course we hope you will have gained a better understanding of how the Linux operating system works through practical example applications. Our final goal will be to construct a simple heating controller with a graphical display and data analysis via a browser.

The origins of GNU and Linux

It is important for anyone using Linux seriously to understand why and how the free GNU/Linux implementation of Unix arose and how it is organised. This allows better understanding of where the boundary of the operating system lies and, most importantly, to work out which piece of software or hardware might be responsible for a problem.

Significant development of Unix [4] began in 1969 at Bell Laboratories in the USA. Ken Thompson wrote the first version in assembler. To get a better idea of what interfaces

Features of the Elektor Linux board

- two-layer board using readily-available components
- no special debugging or programming hardware required
- fully bootable from an SD memory card
- Linux pre-installed
- 180 MHz, 8 MB RAM (32 MB optional), 64 MB swap
- integrated USB-to-RS-232 converter for console access
- relay, external power supply, and pushbuttons for quick testing
- four GPIO pins, 3 A/D channels and a PWM channel on-board
- I²C and SPI buses accessible from Linux
- USB interface for further expansion

and drivers would be needed he wrote, along with Dennis Ritchie, the game 'Space Travel'. From a microcontroller programmer's point of view this approach is easy to understand: when developing an embedded system it is important to plan from the beginning how the software (including hardware drivers and utility functions) will be structured to maximise the reusability of the source code. Ken and Dennis soon worked out which components belonged in the operating system and how the whole thing should be organised. Between 1972 and 1974 they re-wrote the heart of the operating system from scratch using the C programming language, which had also been developed at Bell Laboratories. The operating system, including a C compiler, was distributed to universities free of charge.

At the end of the 1970s AT&T, the carrier behind Bell Laboratories, realised that there was potential to market Unix commercially. Until that time it was normal for software to be shared and exchanged freely. 'Pirating' and other such 'illegal acts' were unheard of. Software was distributed with the goal of improving it collaboratively. This underlying attitude still lies at the heart of the free and open-source software movement [5], [6]. Once AT&T had started to sell Unix it could no longer be exchanged freely. Suddenly, because of the high licence costs, it was no longer feasible to use it in university courses or for self-study. At this time more and more companies started to licence their own Unix variants: one example is Siemens' SINIX, which has its origins in the Xenix version of Unix from Microsoft.

Richard Stallman, at MIT in the USA [7], was not happy that Unix was now in general only available to companies. It seemed that the happy days when Unix was copied and shared between colleagues and friends were over. There was only one solution: a complete new and free version of the Unix system had to be developed from the ground up.

And so GNU [8] (for 'GNU's not Unix') was born in 1983. A huge amount of work lay ahead of Richard Stallman: everything had to be reimplemented in order to create a 100 % free operating system. He would need:

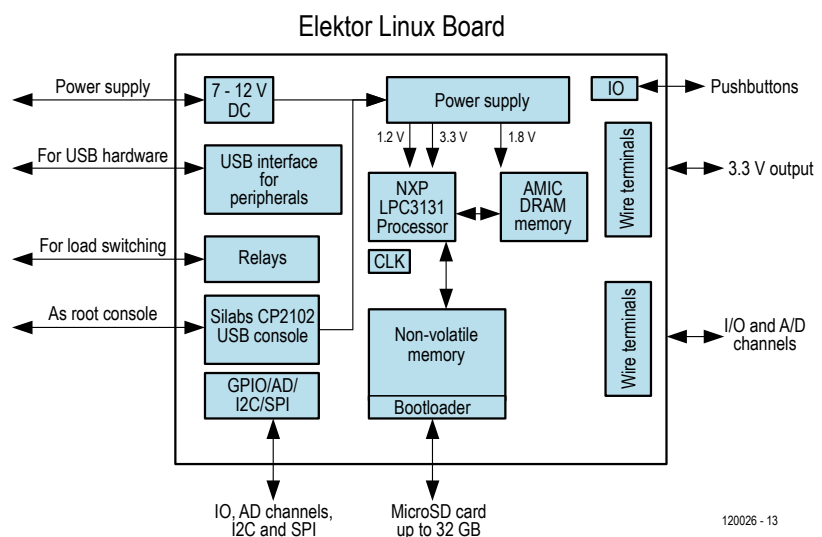


Figure 1. The board makes a powerful basis for custom microcontroller projects. A network interface is also available.

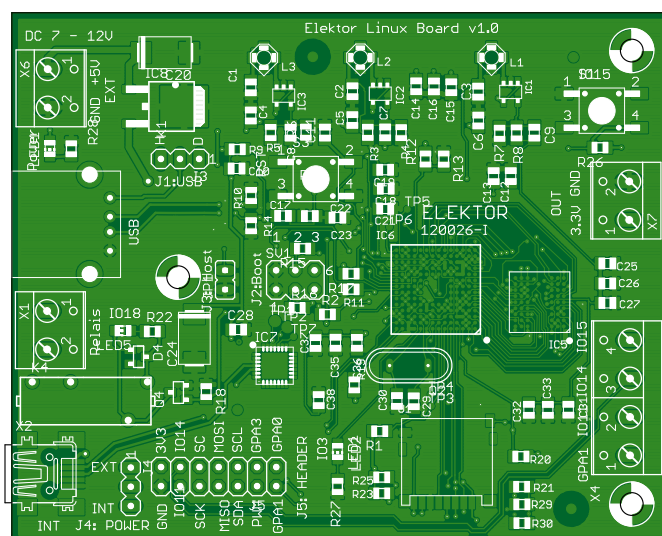


Figure 2. The printed circuit board is available from Elektor ready-populated.

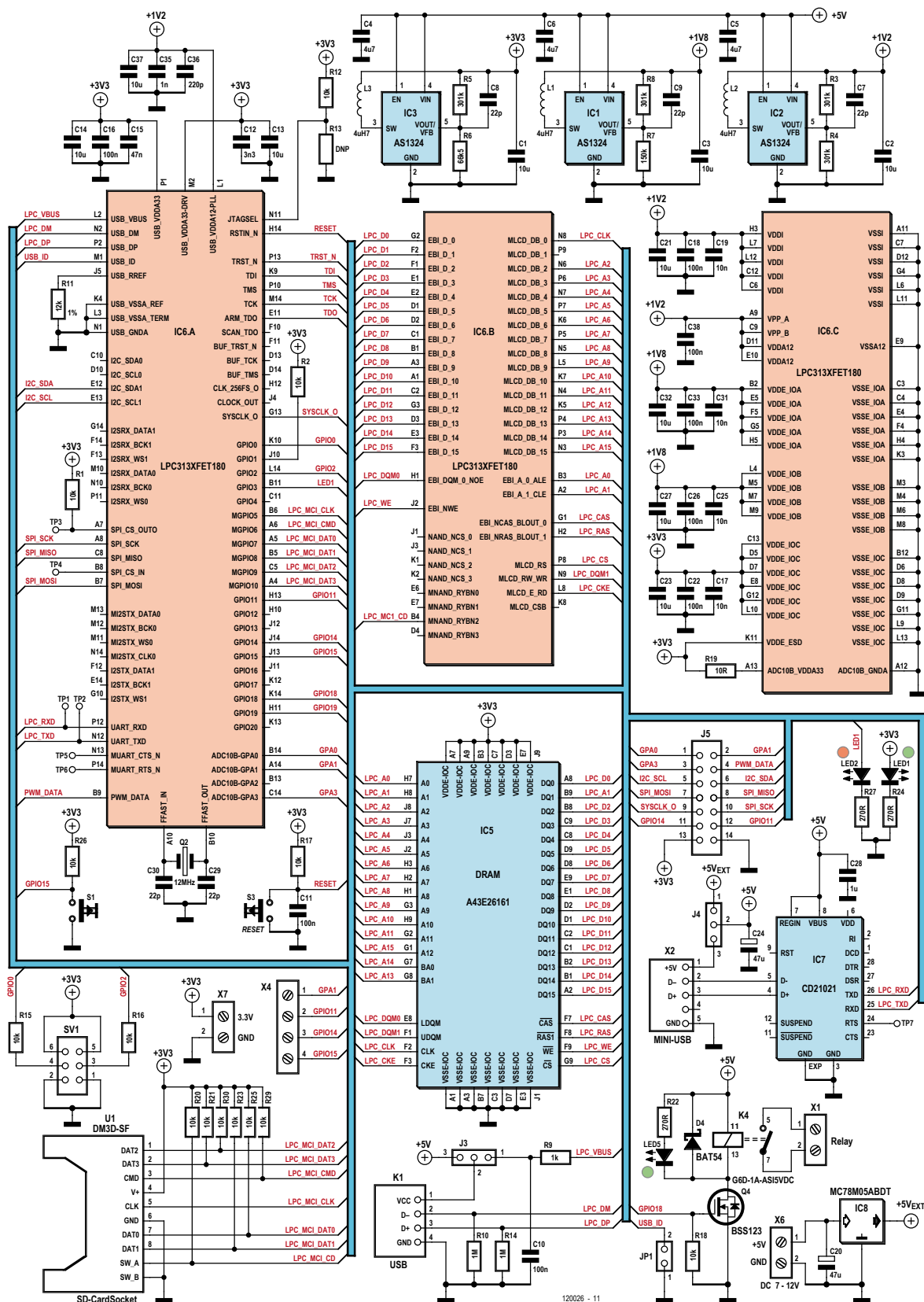


Figure 3. The circuit diagram is surprisingly straightforward for such a powerful board.

- a C compiler, linker and assembler (a 'toolchain')
- a text editor to write source code
- an operating system kernel
- various utility programs
- a root file system for the operating system

By 1990 all the important parts had been assembled, with the exception of the operating system kernel. Richard Stallman knew that it only made sense to start working on the kernel when a stable text editor and compiler were in place.

The beginnings of Linux

At around the same time a Finnish student by the name of Linus Torvalds bought his first x86 computer and wrote a simple terminal program as an exercise to understand the computer better [9]. He installed Minix, a paid-for Unix variant that had been developed by a professor from Amsterdam and his team (and which is still in use today). As he worked on his terminal program, Linus Torvalds saw that it was becoming more and more like an operating system in itself. So as to allow compatibility with the widest possible range of existing software it was clear that the system would have to be POSIX compliant. 'POSIX' defines a standard for how a Unix operating system should appear externally. Fortunately for us, his local bookshop had the relevant POSIX documentation: this was probably in the form of a manual for one of the many other Unix variants. The main thing was that Linus Torvalds had the information about how the system calls were named and with what arguments they were used.

In 1992 the young developer made his creation available on the Internet for free download [10]. He needed a suitable licence under which to release it, and it so happened that he had recently heard Richard Stallman speaking at his university. The GNU GPL (the open source licence used by the GNU project) was ideal. And then something happened which had not been planned: the open source community quickly realised that Linus Torvalds' kernel was the missing element in Richard Stallman's GNU project! It is worth noting that Stallman had already started on a free GNU kernel called 'Hurd', although this does

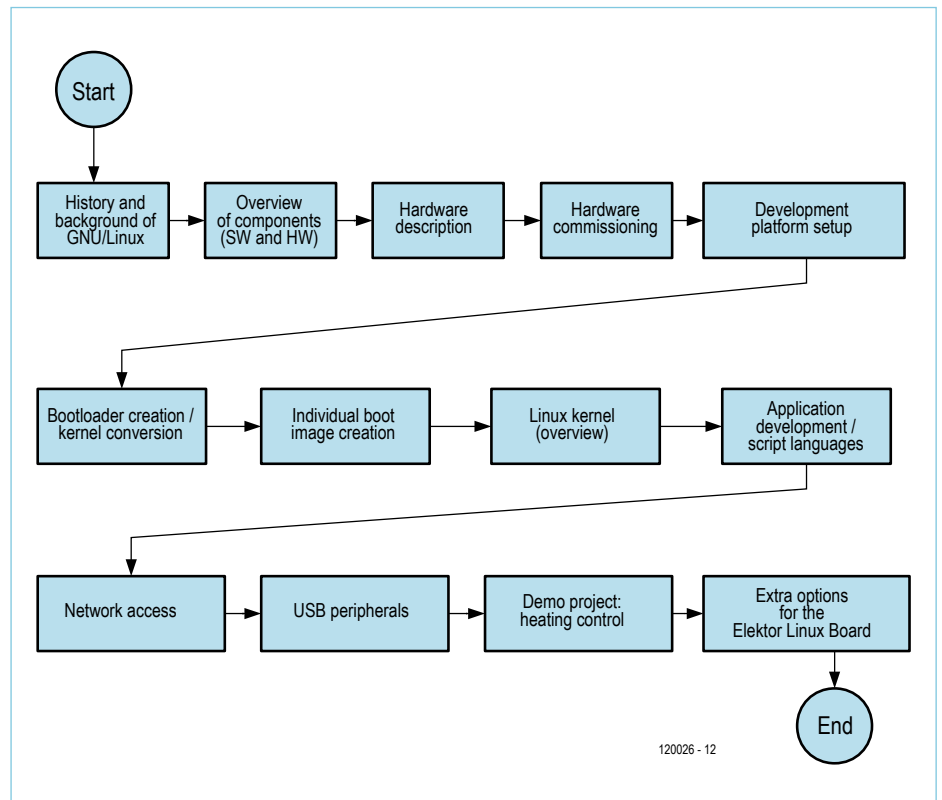


Figure 4. Roadmap of our multi-part introduction to embedded Linux.

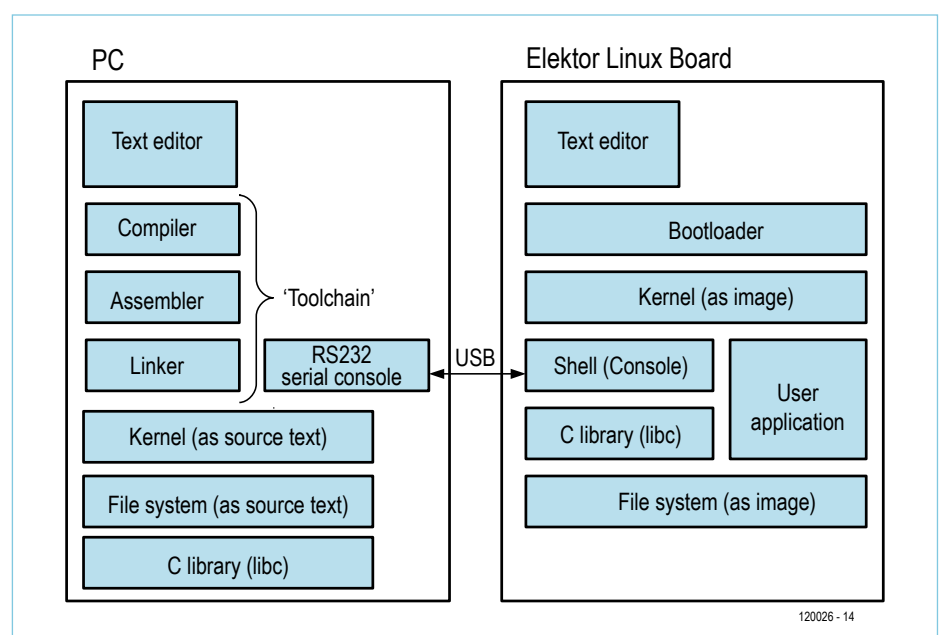


Figure 5. For software development a PC (running Linux) is used in conjunction with the target board.


```

S40networking end
Starting portmap daemon...
S55bootmisc.sh start
net.ipv4.conf.default.rp_filter = 1
net.ipv4.conf.all.rp_filter = 1
System time was Thu Jan 1 00:00:06 UTC 1970.
Setting the System Clock using the Hardware Clock as reference...
hwclock: can't open '/dev/misc/rtc': No such file or directory
System Clock set. System local time is now Thu Jan 1 00:00:06 UTC 1970.
Mon Sep 26 22:13:00 UTC 2011
Saving the System Clock time to the Hardware Clock...
hwclock: can't open '/dev/misc/rtc': No such file or directory
Hardware Clock updated to Mon Sep 26 22:13:00 UTC 2011.
Disabling protocol version 1. Could not load host key
S55bootmisc.sh end
INIT: Entering runlevel: 5
Starting syslogd/klogd: C64 -m 20
done

ELEKTOR EDLK (Built by Poky 5.0) 5.0 elektor-gnublin tty50
http://www.gnublin.org
elektor-gnublin login:

```

Figure 6. Screenshot of the console in action.

nothing to detract from the importance of Torvalds' contribution.

Now, with the GNU project complemented by the Linux kernel, a complete free and open operating system was available for the first time. Strictly speaking it is best to refer to the operating system as GNU/Linux, the 'Linux' part referring to the kernel and 'GNU' to the rest of the operating system supplied by the GNU project.

The big picture

After that brief historical digression it is time to take a look at the overall picture of what components make up our GNU/Linux system (see **Figure 5**). In essence little has changed since the early days: the same basic elements that were needed then are needed for the Elektor Linux board today. For this project we will use several of these original Linux programs. Others we will need to give a wider berth, and we will mention the reasons for this later on.

Text editor

Today's developers are accustomed to using their own particular choice of text editor, with syntax highlighting, code completion and built-in API documentation. In order to make small changes quickly to files on the *Elektor* Linux board we need a text editor that can be used over the Linux console (see below).

There are traditional editors such as 'vi' (or 'vim' in its more user-friendly form) and 'nano' that fit the bill perfectly. Both of these are present in the root file system (see below) of the Elektor Linux board. Linux developers often use the same text editor on their desktop PC, so as to avoid confusion when switching between editors. Another option is the widespread 'Emacs' editor, whose reputation some readers may be familiar with. Emacs was developed by Richard Stallman as part of the GNU project. It is popular with experienced developers because of the wide range of functions it provides; however, beginners might be better off with a more lightweight editor.

Compiler + linker + assembler = toolchain

In order to run programs on a processor it is necessary to convert it to the machine code of the relevant target architecture. The GNU toolchain includes all the software components needed to convert C into machine code. It has been designed so that it is relatively straightforward to add a new instruction set, and so, for example, versions are available for x86, AMD64, AVR, ARM, MIPS, MSP430 and many other processors. The *Elektor* Linux board uses an ARM-compatible microcontroller and so we use the corresponding ARM toolchain. More on this later, when we come to install it.

The kernel

The kernel lies at the heart of the operating system. It originates in the source code written by Linus Torvalds, but since then some ten thousand kernel developers have worked on the code. However, Torvalds has always had the final say on whether changes and extensions are accepted into the kernel or rejected. Any developer not agreeing with his decision is of course free to fork his own version of the kernel, as the whole thing is open source. To date, however, there has been no significant forking of the Linux kernel code. The development of the software is organised using mailing lists, and anyone is allowed to join these lists and make suggestions. These suggestions will be examined by others and discussed.

With the exception of just a few lines of code, the kernel is written entirely in C, and can be simply converted from C to machine code using the GNU toolchain. We will see how this is done at a later point in this series.

File system

Under the Windows operating system it is clear enough that a user's files go in the directory 'Documents and Settings', programs are installed in 'C:\Program Files', and lower-level operating system files are kept in the System32 directory under 'C:\Windows'. Like any other operating system, Windows has its own structure for organising its many program and data files. So naturally we ask how things are arranged in embedded GNU/Linux systems. Here the origins do not lie with Linus Torvalds or Richard Stallman; the common basis for all Unix and Linux file systems was mostly developed incrementally as part of POSIX standardisation. The so-called 'root file system structure' has been further developed by the well-known distributions such as Debian, SUSE and the like. These distributions each offer the user a complete GNU/Linux system with applications already installed, a graphical user interface, and an up-to-date kernel.

To use Linux on our board we will also need to set up a root file system. For our situation a fully-featured desktop version of Linux would be too unwieldy, and a cut-down version of the full system will usu-

Internet Links

- [1] sauter@embedded-projects.net
- [2] www.gnublin.org (site in German only)
- [3] www.elektor.com/120026
- [4] <http://en.wikipedia.org/wiki/Unix>
- [5] http://en.wikipedia.org/wiki/Free_software

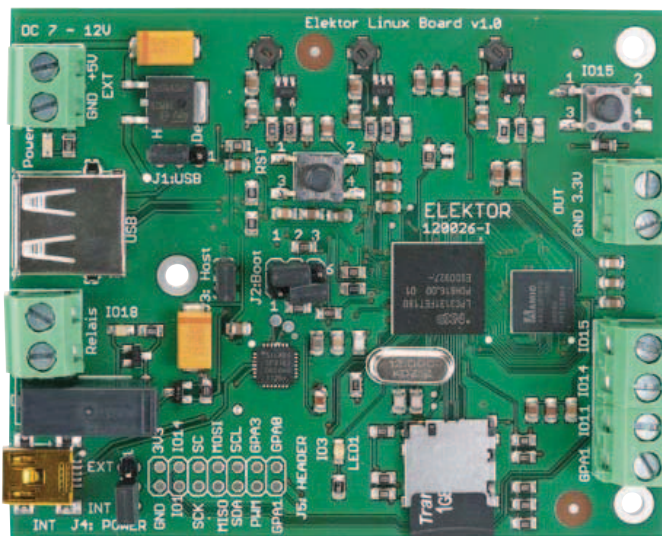
- [6] http://en.wikipedia.org/wiki/Open_source
- [7] http://en.wikipedia.org/wiki/Massachusetts_Institute_of_Technology
- [8] www.gnu.org
- [9] 'Rebel Code: Linux and the Open Source Revolution', Glyn Moody; ISBN 0738206709
- [10] www.kernel.org

ally suffice, with a relatively small choice of programs and libraries. There are specially-written programs that can be used to create custom root file systems; alternatively, all the mainstream distributions offer ready-made versions for ARM processors. More on this topic later.

The standard C library

Applications provide the visible face of any computer or similar product. The operating system sits in the background, driving the hardware, allocating memory, handling communications over the network or other interfaces and much else besides. Now, application writers do not want to spend their time forever rewriting functions to read and write files, manipulate strings and so on. To the developer's rescue comes the standard C library, in its most popular form known as 'libc'. Slimmed-down versions of this library are available that are suitable for embedded systems where computing power and storage are relatively limited compared to desktop PCs. The standard C library provides the interface between the application and the kernel. It also includes a number of commonly-wanted utility functions. The library

is loaded at run-time as required by application programs (it is 'dynamically linked'). This saves memory as a single copy of the library can serve all running applications.



The serial console and shell

The console, which can be compared with the command prompt in Windows, can be used for entering commands, triggering actions (possibly on a remote machine) and displaying results. In this way it provides a user interface to the system. Usually it is used in conjunction with a 'shell', which provides many handy extra features that

make a Linux system easier to operate. We will look at the shell in greater depth later. When Linux is booted on a desktop PC the keyboard and screen provide the traditional root console. (It is usually possible to switch to this console from the graphical user interface by pressing control-shift-F1.) When administering machines remotely it is common to use a protocol such as SSH or, where security is not a consideration, TELNET, to access the root console over a network connection. A third option is to access the console over an RS-232 interface. A PC with a serial port can be used at the other end of this connection, running a terminal emulator program such as HyperTerminal or TeraTerm (under Windows) or picocom (under Linux).

What the future holds

In the next instalment in this series we will look at how the hardware (Figure 1) is arranged. We will look closely at the power supply, the microcontroller, the SDRAM device and the various interfaces. On the software side, we will examine the boot process: thanks to the pre-installed demonstration software (**Figure 6**) the board is ready for experimentation straight away.

(120026)

Elektor Products and Services

- Elektor Linux board, ready built and tested: # 120026-g1
- Free software download

All products and downloads are available via the article support page: www.elektor.com/120026

Platino Controlled by LabVIEW (1)

Although at first blush they appear completely different, Arduino and LabVIEW both are programming environments aimed at people who do not, or do not want to know how to program. Both platforms were designed for quickly developing an application without being slowed down by complex syntax issues or intricate procedures. Reusability of earlier work plays an important role in both environments.

By Clemens Valens (Elektor UK/INT Editorial)

With the possible exception of their success, that's where any similarities end. Where LabVIEW (LV) is a graphical programming language (GPL), Arduino is text based; where LV is a closed commercial package, Arduino is free and open; where the commercial success of LV is actively being pursued by a company, Arduino was simply thrown at the online electronics community. But there is one other thing that LV and Arduino have in common: both platforms see a lot of use in education, at schools and universities. It is therefore not surprising that they finally met when National Instruments (NI) in 2011 introduced their LV Interface for Arduino (LVIFA or LIFA). This interface allows easy control of hardware from LV without having deep pockets. Although it's always been possible to control cheap custom hardware from LV, doing so requires some LV experience that many users lack. LIFA solves this problem by providing a simple serial protocol for communicating with the external hardware. Even though LIFA is targeted at Arduino there is no reason whatsoever to stop there. Anyone capable of implementing the protocol on whatever hardware platform may use this library.

LIFA comes as a free and open source library containing quite a few Arduino style functions. Analogue and digital I/O are available, as are SPI and I²C communications. Although LIFA featuring servo and stepper motor control seems slightly robotics oriented, it also allows continuous sampling at up to about 5 kHz. At the time of writing LIFA version 2.0 had just been released.

NI has done a nice job of making Arduino easy for LV users, but unfortunately they appear to have forgotten to make LV easy for Arduino users. Most LIFA functions have examples that illustrate their use, yet the most basic example of all, how to flash an LED, is sadly missing. Although this should be an easy exercise for the average LV user, the average Arduino user attracted by the power of LV will probably stand clueless.

In this article I intend to show you how to get started with LIFA and LV, assuming that you are comfortable with Arduino. First of all I will walk you through the creation of a Hello World blinking LED example, then we will delve into the modification of existing functions, followed by the creation of your own functions and finally we will add extra hardware to our Arduino platform that we control from LV. To cap it all we will add some shared variables that can be monitored wirelessly over the Internet on an iPad or Android tablet from anywhere on the globe.

Our hardware platform will be Platino as it is compatible with Arduino but has on-board peripherals so you don't have to wire anything up. The examples presented here will also work with standard Arduino hardware and the right peripherals (buzzer, LCD, rotary encoder).

LIFA

Let's be clear about it from the beginning: LIFA is not LabVIEW *on* Arduino, it is LabVIEW *with* Arduino. It is important to understand this difference to avoid unjustified expectations. LIFA is a way of controlling external hardware from LV. It consists of three parts: a kind of server running on the Arduino board, a serial communications protocol and a library of LV functions to control the board. With LIFA you can use Arduino to interact with the real world under control of LV. Without LV it will not work. Okay, this last statement is not completely true, because you can of course implement the LIFA protocol in another program written in like Visual Basic or Qt and use that to control the Arduino. What's important here is that the Arduino is a LIFA slave device and will not do anything until it is ordered to do something.

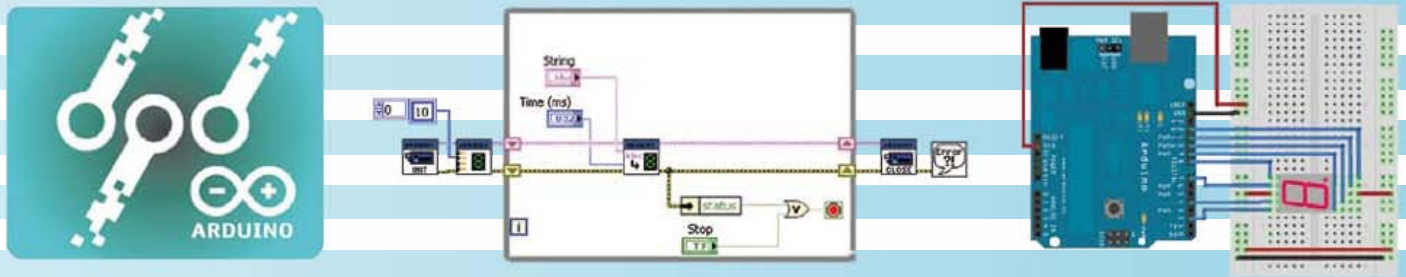
To use LIFA you have to install first LabVIEW (I used version 2011), then NI-VISA (Virtual Instrument Software Architecture, if not installed already) that will allow LV to talk to the serial port (and more) and then LIFA (version 2.1.0.69 at the time of writing, you need version 2 or higher if you want to use Arduino 1.0). You are supposed to do this last step with the VI Package Manager. These are massive files and installing it all takes some time.

When the installation is finished (I suppose that you managed to get Arduino 1.0 up and running all by yourself) you have to load the LIFA serial server sketch into the Arduino board. You can find it in the 'vi.lib\LabVIEW Interface for Arduino\Firmware\LVIFA_Base\' sub-folder. Load the file LVIFA_Base.pde in the Arduino IDE and upload it to the board.

You may run into trouble here if your board does not have 32 KB or more of flash memory. The Arduino Uno or Mega are fine, but older boards with ATmega168 chips are not. The reason for this is the 5 KB stepper motor library included in the sketch. You can deactivate it by commenting out a line in the file LabVIEWInterface.h.

Among the issues you may run into if you use a non-standard Arduino board, e.g. Platino with an ATmega164(P), are compile

An introduction to LIFA, a LabVIEW interface for Arduino



errors spawned by the stepper motor driver library because it does not support the MCU. To prevent this from happening you have to rename or delete the CPP files so they will not be compiled at all. Without stepper motor support and without compiling the CPP files the LIFA sketch will fit into 16 KB devices too.

Once you have the LIFA sketch running on the Arduino you probably would like to see if it works. For this you launch LabVIEW, click **Find Examples** in the main window, select the **Search** tab, search for **Arduino** and discover that there is no example that will run without additional hardware... That's right; they forgot to include the Blink-the-Arduino-LED example. Duh! To fix this omission I will show you here how to make it yourself.

Hello World with a virtual LED

Programming in LV differs a lot from programming in Arduino. Because LV is a graphical 'language' a program is drawn instead of being written. Probably 99% of the very little typing you do in LV is related to constants, comments and documentation. Where in Arduino a program is called a 'sketch', in LV it is called a 'virtual instrument' (VI, LV has its origins in test and measurement applications where lots of instruments are used).

Functions are represented as blocks and data streams are represented by the wires that connect the blocks. The wire colours indicate the type of data being transported. LV is very strict in this regard and you simply cannot accidentally mix up wires of different colours. Also, if you forget to connect an important function input, LV will not let you run the VI.

Being an LV novice I preferred to start simple, being a microcontroller enthusiast I wanted to blink an LED. This can be done easily in LV as it has LEDs. We're off.

From the LV main window select **Blank VI**. Two windows will open, one named 'Block Diagram', the other is called 'Front Panel'. The drawing is done in the block diagram; the LED will show up on the front panel. Right-click somewhere in the block diagram to bring up the functions menu. Click the down arrow to expand it (**Figure 1**).

To make a continuously blinking LED I chose to use an endless while loop with a delay. You can find it in the **Programming -> Structures** palette. Of course there is more than one way to skin a cat, also in LV, and another possibility would be to use the timed loop from the **Programming -> Structures -> Timed Structures** palette, but it looks more intimidating. To make the loop

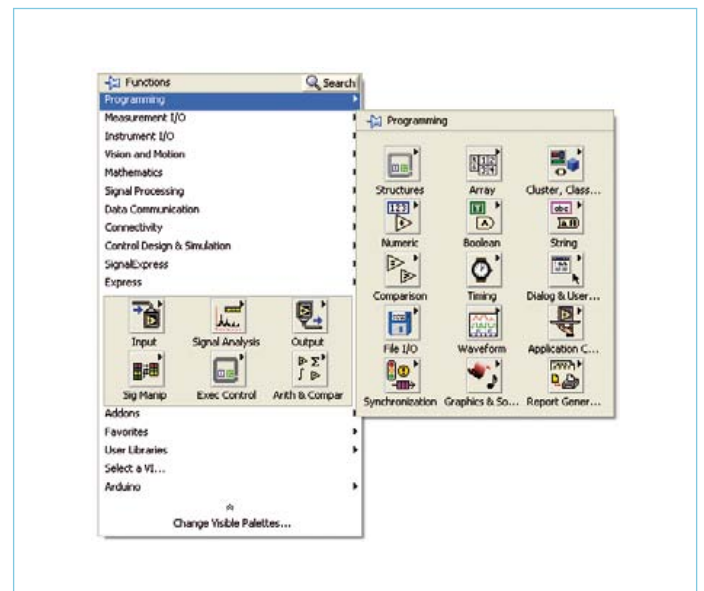
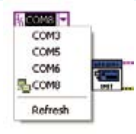


Figure 1. The Functions context menu. Click the Search button to quickly locate a function that may be hidden deep down a function sub palette.

The right mouse button click

One of the difficulties the LV novice encounters is finding the functions he needs. Functions are grouped by type in so-called palettes, but since there are so many palettes it is not easy to find the one you want and of which you did not even imagine its existence. For this problem LV has a powerful solution: the right mouse button click. Whenever you are lost, click right and LV will show you a context menu with the most probable options for the situation you are in. Need a function? Click right and look at the palette options. Need a data type? Right-click and ask LV to create it for you. Idem for controls, indicators, advanced editing options, you name it, it will probably be in the context menu right in front of your eyes.

Do not abort



When developing an application in LV you will be tempted often to abort the execution of the VI you are working on by pressing the button with the red dot. In many cases this is not a problem, but sometimes it is, especially when you use serial ports.

It is important to properly close the serial connection in LV to prevent the communications between the VI and your board getting messed up. If you're lucky you may see an Error 5002 message, if not your setup simply won't work. This happens most often when the VI does not go through the Arduino Close sub-VI because you pressed the abort button. It is extra annoying when you are working on Arduino and LV code at the same time to fine tune your application, because you will not be able to upload any code to your Arduino board as the serial port is already in use.

You can see in LV that a port is open (or was not closed) when there is a little icon in front of the COM port when you open the drop down list (see screenshot). To get out of this situation you have to either quit LabVIEW to get the COM port back or find another way to close the port. If your VI has a path to the Close sub-VI you can restart the VI and guide it through the Close sub-VI to recover the serial port. Therefore always make sure that you can get out of endless loops to close your VI properly. Add a Stop button if necessary.

Avoid using the Abort button.

endless we will have to set its `Loop Condition` (the square with the red dot in the lower right-hand corner of the loop) to False. Do this by placing the mouse on the square in such a way that its left side starts blinking (the mouse cursor changes into a little reel of wire), then press the right mouse button (see inset) and select `Create Constant` from the menu that pops up. A green square with an F(false) in it is created, meaning that the loop will never end. Note the dashed green line between the two squares; it indicates a Boolean data stream.

From the `Programming -> Timing` palette I picked the `Wait Until Next ms Multiple` block to slow down the endless loop. You have to place it inside the loop. Now hover the mouse over the left of the timer block to find the `millisecond multiple` input. When it appears use the right mouse button to bring up the context menu and then select `Create -> Constant` (**Figure 2**; this is slightly different from setting the `Loop Condition`). You will now have a little rectangle with a blue rim and a zero in it. Change the zero to, say, 250. This means that the loop will be executed every 250 ms.

Now comes the hard part: the LED toggle mechanism. Again, several techniques can be used, but I chose to use the `Loop Iteration` box, the little blue square in the lower left-hand corner of the loop. The value of this box is incremented every time the loop is executed, so if we continuously test this value for even or odd we end up with a toggling result. An odd/even test is easy in the binary domain by testing the least significant bit of the value. To do this we perform a logical AND (get it from the `Programming -> Boolean` palette) of the value with a constant value of 1. First wire one input of the AND gate to the loop counter to change the data type of the gate from Boolean to Integer, then create the constant of 1 by right-clicking the remaining input of the AND gate. The order is important here. Supposing you had created the constant first, you would have obtained a Boolean that cannot be AND-ed with an integer, causing LV to refuse to connect the other AND input to the loop counter.

The result of the logic AND is now also an integer and it has to be converted to a Boolean first before it can be connected to an LED. We can do this by adding a `Greater?` function from the `Programming -> Comparison` palette. If you place it close enough to the AND-gate, LV will make the connection automatically. Connect a constant of zero to the other input of the comparison function.

The output of the `Greater?` function is a Boolean that we can connect to an LED. To do this, right-click the output, select `Create -> Indicator` and an LED will appear in both the block diagram and the front panel (use Ctrl-E to move quickly between these two windows).

That's it; our *LV Hello World blinking LED VI* is now ready (**Figure 3**). Click the Run button on either the block diagram of the front panel to see the LED flash at a rate of 2 Hz. To stop it you will have to press the Abort button (see inset).

To finalise it, if you like, you can move all the bits around to create a pretty looking VI, or you can let LV clean it up for you by using the `Clean Up Selection` function (by clicking the button with the broom, selecting it from the Edit menu, or by pressing Ctrl-U). When done, save it.

With a real LED

Now that you have an idea of how to go about programming in LV we will continue by extending the Hello World example to the hardware, that is, instead of making the LV LED blink, we will now make the Arduino LED blink. The LED is the one connected to digital pin 13 (Arduinospeak) also known as port B pin 5 (PB5). The steps to do this in LV are very similar to those in an Arduino sketch. You have to select the board and the serial port, make digital pin 13 an output (setup) and then toggle it (loop). In LV there is one extra step at the end because you have to close the serial port when you're done.

In the VI we take these steps as follows:

Arduino prepare

From the `Arduino` palette get the `Init` block (**Figure 4**) and place it to the left of the loop in the block diagram. Hover over its inputs and notice that they all have default values (the values between round brackets) except for the `VISA resource` and the `error in`. The latter can be left unconnected, not the first, so do a right-click on this one and create a constant. This constant is a drop-down list from which you select the serial port that is used by the Arduino board. The other inputs can be left at their default values, even if you have an Arduino Mega.

Arduino setup

From the `Arduino -> Low Level` palette get the `Set Digital Pin Mode` block and place it between the `Init` block and the loop. Connect the pink `Arduino Resource` pins of the two

blocks, and also connect the error out of the Init block to the error in of the Set Digital Pin Mode block. Create a constant on the Digital I/O Pin input and set it to 13. Create another constant on the Pin Mode input and set it to output.

Arduino loop

From the Arduino -> Low Level palette get the Digital Write Pin block and place it inside the loop. Connect its left Arduino Resource and error pins to their counterparts on the right side of the Set Digital Pin Mode block. Connect the Digital I/O Pin input to the pin number constant 13 that you created during the previous step. Connect the Value input to the output of the AND gate.

LabVIEW extra step

From the Arduino palette get the Close block and place it to the right of the loop. Connect its left Arduino Resource and error pins to their counterparts on the right side of the Set Digital Pin Mode block. Do a right-click on its error out pin and from the Dialog & User Interface Palette entry in the context menu get the Simple Error Handler. If you hover this function block to the right of the Close block, LV may connect it automatically for you. If not you will have to do it yourself. Finally, click right on the green square with the F that is connected to the loop's stop condition and select Change to Control from the context menu. This will create a pushbutton on the front panel that allows you to stop the VI in a controlled way (see inset "Do not abort").

Your VI should now look something like **Figure 5**. If you made a mess of your block diagram, now is a good time to press Ctrl-U to clean it up, then save your work.

Run the VI. If all is well the LED on the Arduino board should start to flash at the same rate as the one on your computer screen. The real one may not blink as regularly as the virtual one, I suppose due to real-time and USB issues within Windows, but it should not go slower or faster.

If the real LED does not start flashing but the virtual one does, you probably have entered the wrong serial port for the board. Click the Stop button and you will probably see an error 5005 "Unable to find Arduino". You do not see this error before stopping because the error dialog is at the end of the VI. If you connect it directly to the Init block, you will see it earlier, but you will also get more because the other Arduino related functions will produce errors too.

In the second part of this article we will dig in deeper and really get our hands dirty. Although you may not become a LabVIEW expert, you're sure to get to know LIFA very well.

(120208)



Figure 2. A typical context menu that pops up when you do a right mouse button click on a function input or output.

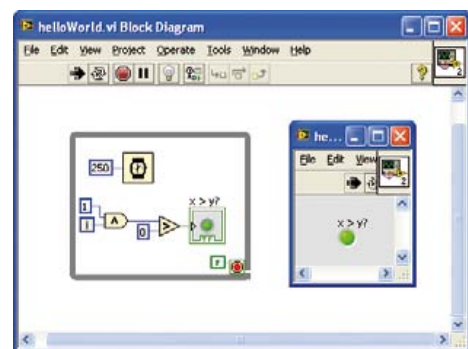


Figure 3. My First Virtual Instrument, or how to flash a virtual LED at 2 Hz using LabVIEW. The smaller window with the gray background is the front panel that holds the flashing LED.

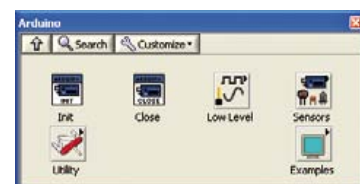


Figure 4. The Arduino function palette as seen from the block diagram. The embossed squares with a black triangle in the upper right corner lead to sub palettes and examples too.

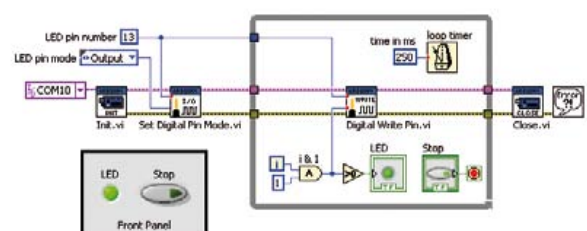


Figure 5. The Hello World VI from Figure 3 extended so that it will also flash a real LED on the Arduino board. Note the Stop button that allows a clean exit.

Preamplifier 2012 (2)

Part 2: Moving-Coil / Moving-Magnet (MC / MM) board

By Douglas Self (UK)

Just in case you didn't know, vinyl records are making a comeback and there are even under-25 musicians releasing new material on CD cheerfully along with vinyl, preferably of the 180-gram variety. Also, high-end turntables are available at extragalactic prices but none of this makes any sense if you do not have a preamplifier to match your MC or MD cartridge optimally and that's exactly what the present design does — rather successfully.

Referring back to the block diagram of the Preamplifier 2012 shown in part 1 of the article [1], this month we discuss the blocks identified as 'MC preamp', 'Load synth', 'MM preamp', 'Bandwidth definition filter' and 'Switched gain'. Note that the switch drawn with 'Switched gain' block is actually an on-PCB jumper block. All units are comprised on a single circuit board, the second of a total of seven that make up our very high end audio control amplifier. Let's see how it all works by taking a tour of the circuit diagram in **Figure 1**.

Moving-Coil (MC) stage

This stage built around transistors T1-T4 and opamps IC1A and IC2A gives very low noise with the low impedances of moving-coil cartridges. It provides a fixed gain to its output of +30 dB. Gain switching to cope

with the very wide range of MC cartridge sensitivities is done later in the switched-gain stage. There are no compromises on noise or headroom with this architecture, and no necessity to switch the gain of the MC stage, which simplifies things considerably.

The total gain of the stage is actually +45 dB, to allow a sensibly high value of feedback resistance defined by R8 and R9. Only part of this gain is used, tapped off via C7. The extra 15 dB of gain causes no headroom problems as the following MM stage will always clip long before the MC stage. The DC conditions for the 2SA1085 input transistors are set by R3 and R4. The DC conditions for the opamp IC1A are set independently by the DC integrator servo IC2A, which enforces exactly 0 V at the output. This MC stage design gives a 1 dB improve-

ment in noise performance (for 3.3 Ω and 10 Ω source resistances) compared with earlier versions of this circuit. This results from using four paralleled 2SA1085 pnp transistors, which should be easier to obtain than the obsolete 2SB737; the latter can however be used if you have them.

Component positions R1 and C1 are provided so the cartridge loading can be modified. This has only a marginal effect on MC cartridge response in most cases because the cartridge impedance is so low. However, if you want to experiment then the appropriate range for R1 is 10 Ω - 1 k Ω , and for C1 0 – 10 nF.

Moving-Magnet (MM) stage

This is a relatively conventional stage, except that it uses multiple polystyrene capacitors to obtain the required value

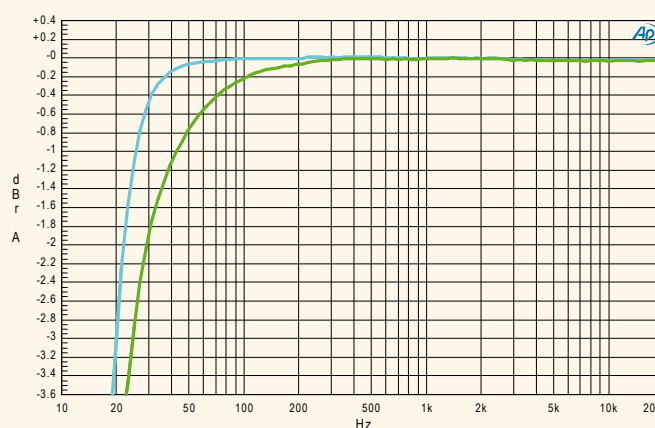
Performance graph

MC/MM board # 110650-2 only.

Test equipment: Audio Precision Two Cascade Plus 2722 Dual Domain (@Elektor Labs).

Here we have the AP-2 supplying an amplitude corrected signal according to RIAA pre-equalisation curve. This allows the deviation from the ideal RIAA curve (amplitude error) to be visualised conveniently. The curve with the higher roll-off point was plotted with the IEC Amendment relay energised. The error at 20 kHz is less than 0.06 dB, measured on the left-channel MC input. Measurements on the right-channel MD input gave practically identical results, the curves matching extremely closely.

In conclusion it is safe to say that the investment in a large number of relatively costly polystyrene capacitors in this section of the Preamplifier 2012 is justified.



(polyester capacitors have worse tolerance and introduce non-linear distortion) and to improve RIAA accuracy (because random errors in the capacitor values tend to cancel). Multiple RIAA resistors R22-R23 and R24-R25 are used to improve accuracy in the same way. The value of C12 is large as the IEC amendment is not implemented in this stage.

The HF RIAA characteristic is corrected for the relatively low gain of the stage by R26, R27, and C22. Once again two resistors are used to improve accuracy, and C22 is polystyrene.

Note that an NE5534A is used here for IC3 as it is quieter than half an NE5532, and considerably quieter than an LM4562 with its higher current noise. The high inductance of an MM cartridge makes low current noise important. Cartridge loading, and capacitance in particular, has a much greater effect on MM cartridges. Component positions R13 and C8 are provided so it can be modified. The appropriate range for C8 is 0–330 pF. Adding extra loading resistance is rarely advocated; if used here it will partly undo the noise reduction given by the load synthesiser. The lowest recom-

mended value for R13 is 220 k Ω .

The load synthesiser

A load-synthesis circuit around IC4 is used to make an electronic version of the required 47 k Ω loading resistor from the 1 M Ω resistor R16. The Johnson noise of the resistor is however not emulated and so noise due to the rising impedance of the MM cartridge inductance is eliminated. R16 is made to appear as 47 k Ω by driving its bottom end in anti-phase to the signal at the top. IC4B shows a high impedance to the MM input while IC4A is an inverting

MM/MC Board Performance

Test conditions: supply voltage ± 17.6 V, B = 80 kHz; measured at Volume/Balance/Tone control board output (# 110650-1); volume set to 1 V out.

Test equipment: Audio Precision Two Cascade Plus 2722 Dual Domain (@Elektor Labs)

MD: 5 mV in, 1 kHz, JP1/2 = 15 dB (source 750 Ω)	THD+N S/N S/N S/N (input shorted)	0.008 % 82 dB 86 dBA 88 dBA
MC: 0.2 mV in, 1 kHz, JP1/2 = 15 dB (source 1 Ω)	THD+N S/N S/N	0.016 % 76 dB 79.5 dBA
MC stage gain		29.8 dB

Low roll-off (–3 dB)	19.8 Hz (L) 20 Hz (R) 23.3 Hz (L, IEC Amendment on) 24.8 Hz (R, IEC Amendment on)
Deviation from straight line:	–0.06 dB (100 Hz to 20 kHz)

Gain definitions on JP1/JP2 (dB)	L	R
0	0	0
5	5.22	5.23
10	10.95	10.97
15	14.71	14.72
20	19.52	19.51

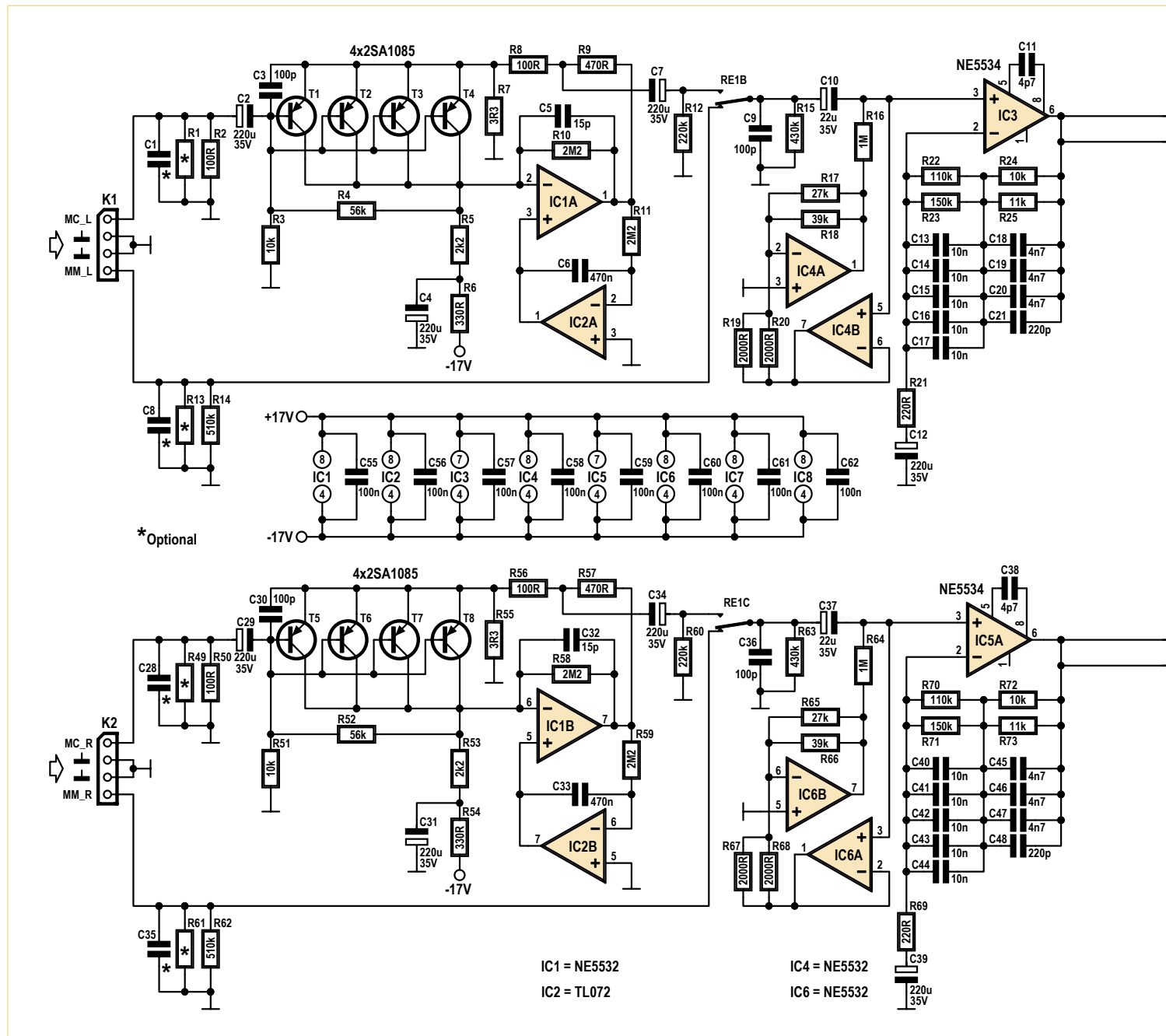


Figure 1. The circuit diagram of the moving coil / moving magnet preamplifier section of our Preamplifier 12. Everything is designed with low noise in mind, as well as perfect adaptability to a wide variety of MC or MD cartridges out there.

stage. Multiple resistors R19-R20 and R17-R18 are used to improve gain accuracy and therefore the accuracy of the synthesised impedance.

Subsonic filter

This is a two-stage 3rd-order Butterworth highpass filter that is -3 dB at 20 Hz. Multiple resistors R28-R29 and R30-R31 are again used to improve accuracy. My pre-

vious preamp designs have used a single-stage version of this, but I have found the two-stage configuration is preferred when seeking the best possible distortion performance [2]. An LM4562 is used here (IC7A) as

it significantly reduces distortion.

The IEC amendment is an extra LF roll-off that was added to the RIAA spec at a

mation, but saves an opamp stage and is accurate to ± 0.1 dB down to 29 Hz. Below this the subsonic filter roll-off begins and the accuracy is irrelevant.

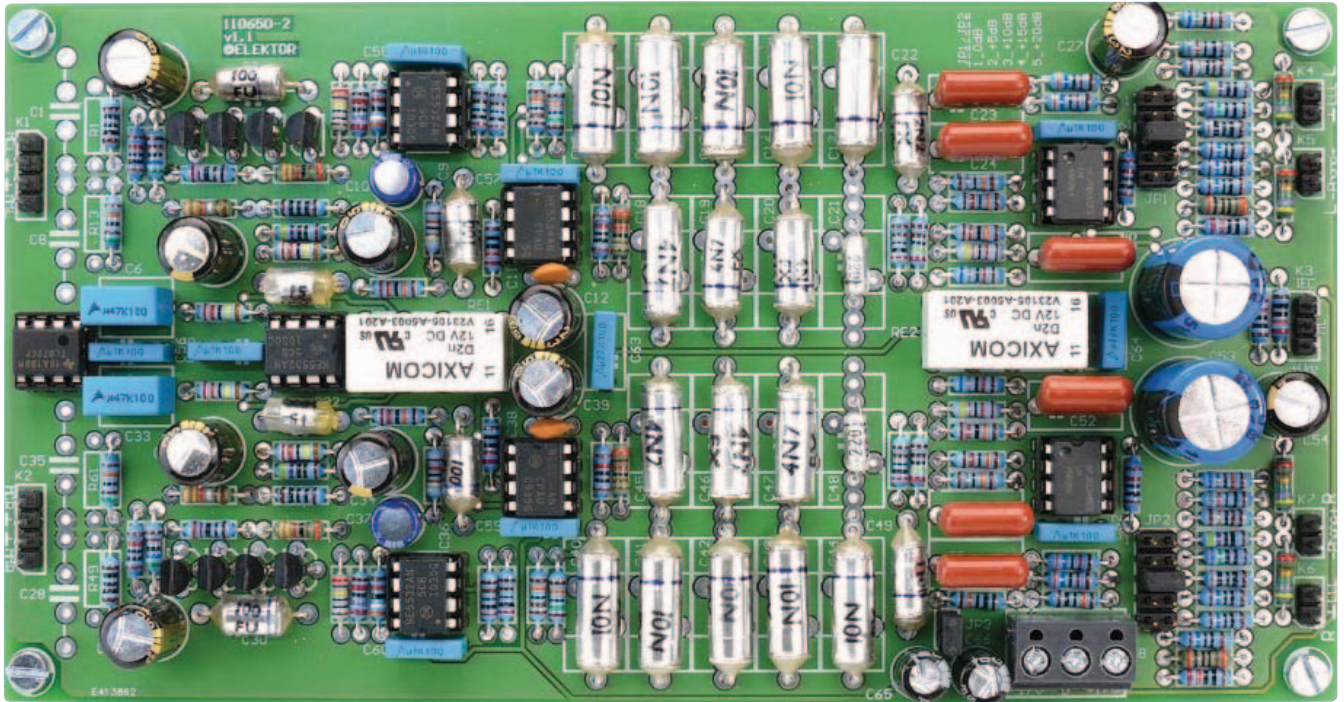


Figure 3. Fully assembled and tested MM/MD board “escaped from the Elektor Labs”.

The switched-gain stage

This stage around IC7B allows every individual MC and MM cartridge on the market to receive the amount of gain required for optimal noise and headroom. The gain is varied in 5 dB steps by a jumper on jumper block JP1 selecting the desired tap on the negative-feedback divider R36–R45. Each divider step is made with two paralleled resistors to get the exact value required, and improve accuracy. R35 provides continuity of DC feedback when the switch is altered.

The drive signal to the Log-Law Level LED stage (LLLL) is tapped off via R47 and appears on connector K4. The LLLL circuit and circuit board will be discussed next month.

Construction

The circuit is constructed on double-sided through-plated printed circuit board # 110650-2 (note number) of which the silkscreen (component overlay) is shown

in **Figure 2**. As with the board we discussed in the previous instalment, assembly is largely a routine matter since only through-hole parts and conventional soldering are involved. For assembly we again recommend the use of a grill or the even better a flip-over type of PCB assembly jig. Assuming you have positively identified each and every part using the components list, the flip-over jig enables the parts leads to be inserted first. Next, the parts are held securely in place at the top side of the board by a thick layer of packaging foam and a clamp-on panel. The board then gets flipped over allowing the wires to be soldered one by one without the parts (now at the underside) dropping or dislocating. Experienced users do the low-profile parts first for obvious reasons.

The end result should be a board that's as thoughtfully built as the circuit was designed — check your personal effort against our prototype pictured in **Figure 3**.

(110651)

References

- [1] Preamplifier 2012 part 1, Elektor March 2012; www.elektor.com/110650.
- [2] Peter Billam 'Harmonic Distortion in a Class of Linear Active Filter Networks', *Journal of the Audio Engineering Society* June 1978 Volume 26, No. 6, p426.

COMPONENT LIST

Resistors

(1% tolerance, metal film, 0.25W)
 R1,R13,R49,R61 = optional, see text
 R2,R8,R50,R56 = 100Ω
 R3,R24,R35,R51,R72,R83 = 10kΩ
 R4,R52 = 56kΩ
 R5,R53 = 2.2kΩ
 R6,R54 = 330Ω
 R7,R55 = 3.3Ω
 R9,R38,R57,R86 = 470Ω
 R10,R11,R58,R59 = 2.2MΩ
 R12,R32,R60,R80 = 220kΩ
 R14,R62 = 510kΩ
 R15,R63 = 430kΩ
 R16,R64 = 1MΩ
 R17,R65 = 27kΩ
 R18,R66 = 39kΩ
 R19,R20,R26,R67,R68,R74 = 2.00kΩ
 R21,R45,R69,R93,R97,R98 = 220Ω
 R22,R70 = 110kΩ
 R23,R71 = 150kΩ
 R25,R73 = 11kΩ
 R27,R75 = 2.4kΩ
 R28,R29,R76,R77 = 36kΩ
 R30,R78 = 180kΩ
 R31,R79 = 120kΩ
 R33,R81 = 43kΩ
 R34,R46,R82,R94 = 68kΩ
 R36,R84 = 820Ω
 R37,R85 = 1.3kΩ
 R39,R87 = 750Ω
 R40,R88 = 300Ω
 R41,R42,R43,R89,R90,R91 = 160Ω
 R44,R92 = 200Ω
 R47,R48,R95,R96 = 47Ω
 R99,R100 = 100kΩ

Capacitors

C1,C8,C28,C35 = optional, see text
 C2,C4,C7,C12,C27,C29,C31,C34,C39,C54 = 220μF 35V, 20%, diam. 8mm, lead spacing 3.5mm
 C3,C9,C30,C36 = 100pF 630V, 1%, polystyrene, axial
 C5,C32 = 15pF ±1pF 160V, polystyrene, axial
 C6,C33 = 470nF 100V, 10%
 C10,C37 = 22μF 35V, 20%, diam. 6.3mm, lead spacing 2.5mm
 C11,C38 = 4.7pF ±0.25pF 100V, lead spacing 5mm
 C13-C17,C40-C44 = 10nF 63V, 1%, polystyrene, axial
 C18,C19,C20,C45,C46,C47 = 4.7nF 160V, 1%, polystyrene, axial
 C21,C48 = 220pF 630V, 1%, polystyrene, axial
 C22,C49 = 2.2nF 160V, 1%, polystyrene, axial
 C23,C24,C25,C50,C51,C52 = 220nF 250V, 5%, polypropylene, lead spacing 10mm
 C26,C53 = 1000μF 35V, 20%, diam. 13mm, lead spacing 5mm
 C55-C62 = 100nF 100V, 10%, lead spacing 7.5mm
 C63,C64 = 220nF 100 V, 10 %, lead spacing 7.5 mm
 C65,C66 = 100μF 25V, 20%, diam. 6.3mm, lead spacing 2.5mm

Semiconductors

T1-T8 = 2SA1085, Hitachi, e.g. Reichelt.de # SA 1085; RS Components # 197-9834
 IC1,IC4,IC6 = NE5532, e.g. ON Semiconductor type NE5532ANG
 IC2 = TL072

IC3,IC5 = NE5534, e.g. ON Semiconductor type NE5534ANG
 IC7,IC8 = LM4562, e.g. National Semiconductor type LM4562NA/NOPB

Miscellaneous

K1,K2 = 4-pin straight pinheader, pitch 0.1" (2.54mm)
 Socket headers for K1,K2
 K3 = 3-pin straight pinheader, pitch 0.1" (2.54mm)
 Socket header for K3
 K4-K7,JP3 = 2-pin straight pinheader, pitch 0.1" (2.54mm)
 Socket header for K4-K7
 Jumper for JP1,JP2,JP3
 JP1,JP2 = 10-pin (2x5) pinheader, pitch 0.1" (2.54mm)
 K8 = 3-pin screw terminal block, lead pitch 5mm
 RE1,RE2 = relay, DPDT, 12V/960Ω, 230V/3A, PCB mount, TE Connectivity/Axicom type V23105-A5003-A201
 PCB # 110650-2 (www.elektorpcbservice.com)

Note: parts available from Farnell (but not exclusively), except T1-T8 and PCB 110650-2.

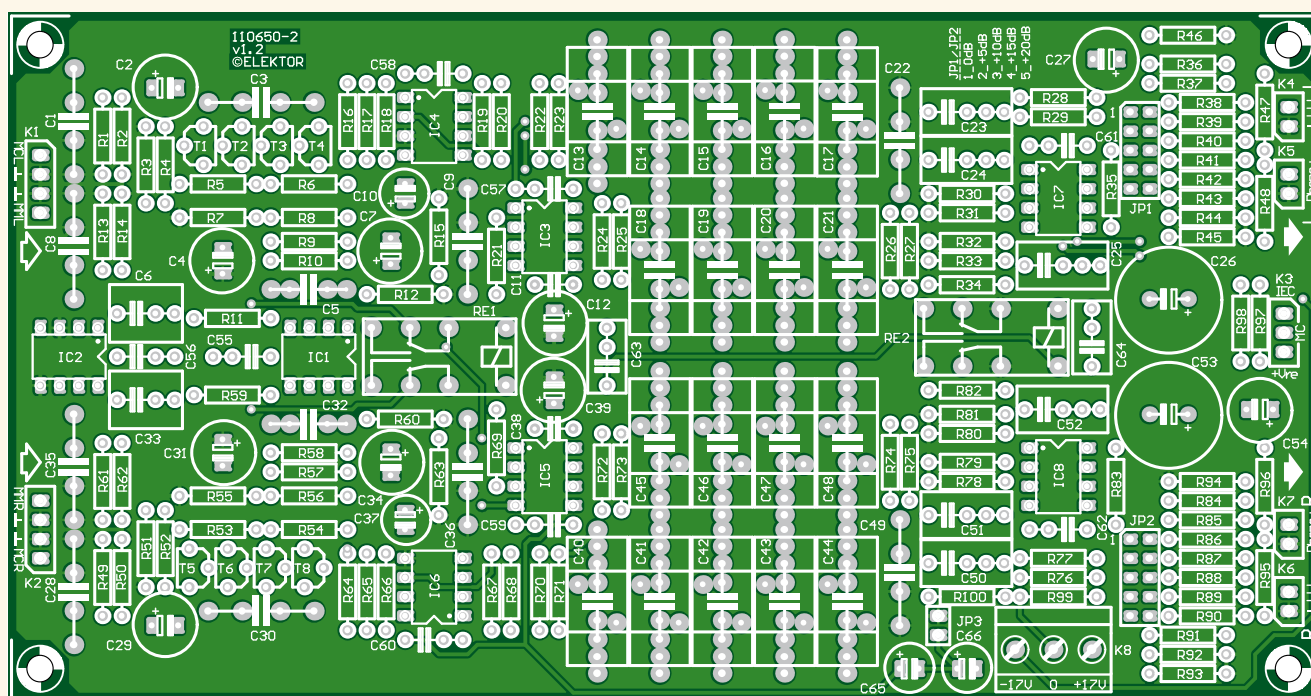


Figure 2. Component overlay of the MM/MC board. The high quality ready-made board is available from ElektorPCBservice.com.

Lossless Load

Keeps energy waste low

By Carlo Cianferotti (Italy)

While the title might sound controversial (a *load* always dissipates some power), the concept presented in this article is spot on: it mimics a load to in-vehicle circuitry that checks for lamp faults. The circuit is great whenever a glass lamp gets replaced by an energy-saving LED substitute. Remarkably, it does not torch extra energy like a shunt would do. Instead, the Lossless Load briefly stores the energy needed to trick the fault circuitry and feeds it back into the car's electrical system when appropriate.



Whenever you replace one of your car's lamps (head/tail/brake/indicator/boot/parking etc.) with an LED aftermarket equivalent, one problem often arises: the lamp failure monitor built into your car's electrical circuitry faithfully responds by making a lamp fault indicator come on when there's nothing wrong with the LED unit. The (supposed) error can be traced back to the much smaller current drawn by the LED unit compared to that of its incandescent counterpart. In fact, if you buy an LED replacement

lamp, it often comes with a bulky power resistor for wiring in parallel with the energy efficient LED just to cheat the lamp failure monitor.

Energy-wise, this workaround is widely off the mark. One of the benefits of LED lighting is the reduced power requirement. And saving power on one side while wasting it on the other is just plain wrong. This shunt resistor can also get pretty hot and problems might arise in the car's plastics nearby. A simple step-up switching converter capa-

ble of feeding up to 4 amps back to the failure monitor can be used to overcome this problem. "Another Fine Mess?" No, a challenge.

Some theory

Take a look at the schematics of the standard circuit to see how the problem gets solved. **Figure 1** shows the original configuration drawing, say, 1.75 A from the vehicle battery. The coloured block represents the in-car lamp failure monitor. From **Figure 2**

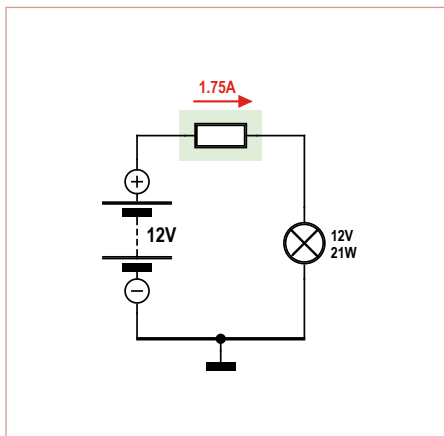


Figure 1. Standard current flow in a car's lamp circuit. There's about 1.75 A flowing through the failure monitor circuitry.

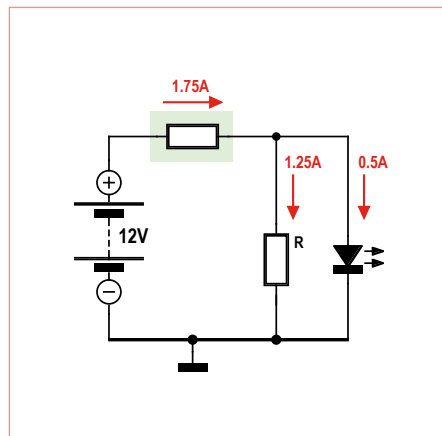


Figure 2. To trick the lamp failure monitoring circuit, we need 1.25 amps to flow besides the current through the LED replacement unit.

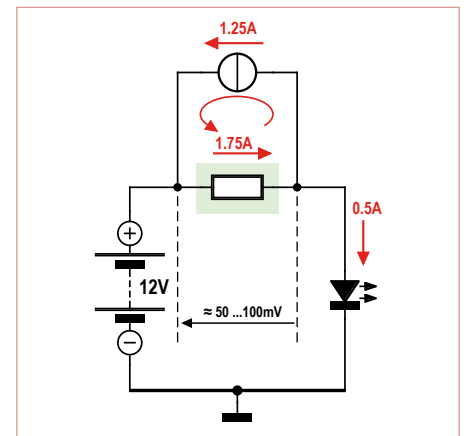


Figure 3. To trick the monitoring circuit, a 1.25 A current source could be connected as shown.

it follows that about 15 watts ($12\text{ V} \times 1.25\text{ A}$) needs to be dissipated in a shunt ('bleeder') resistor after replacing the original lamp with a LED equivalent, in order to have the same current flowing through the lamp failure monitor. In practice a little less power could be wasted, since the trip level is very likely lower than the nominal current.

Now suppose we connect a current source as shown in **Figure 3**. The current flowing through the lamp failure monitor is still 1.75 A, but the battery effectively only supplies the 0.5 A or so effectively used by the LED lamp unit. This way we greatly reduce the power otherwise wasted.

Unfortunately, an ideal current source does not exist as a single component, so we have to design a circuit that mimics one. A simple and affordable circuit would be desirable. We should also be aware of the fact that an ideal current source is nonexistent and that some dissipation losses can not be avoided. However, with the circuit presented here, losses are reduced by a factor of ten compared to those caused by a bleeder resistor.

In a practical setting

Since we are starting off with a voltage that's slightly lower than the battery voltage itself and we want current to be forced back into the battery, we need a step-up converter. To keep costs and parts count low, a popular current-mode PWM controller in an 8-pin DIP housing will be at the heart of our circuit. For the same reason we do not measure the current consumption with a feedback loop, but instead implement a simple MOS peak control loop. Circuit analysis, simulations and prototype testing have shown this to be a more than adequate solution for achieving the intended current within a few hundred milliamps, even with large variations in battery voltage and the inherent voltage drop across failure monitor circuits.

One controller

Let's have a look at the operation of the PWM controller by examining its block diagram, drawn in **Figure 4**. The oscillator frequency can be set as required by selecting the appropriate combination of R_4/C_6 (see **Figure 5**). The main function of the PWM block is to control the peak current meas-

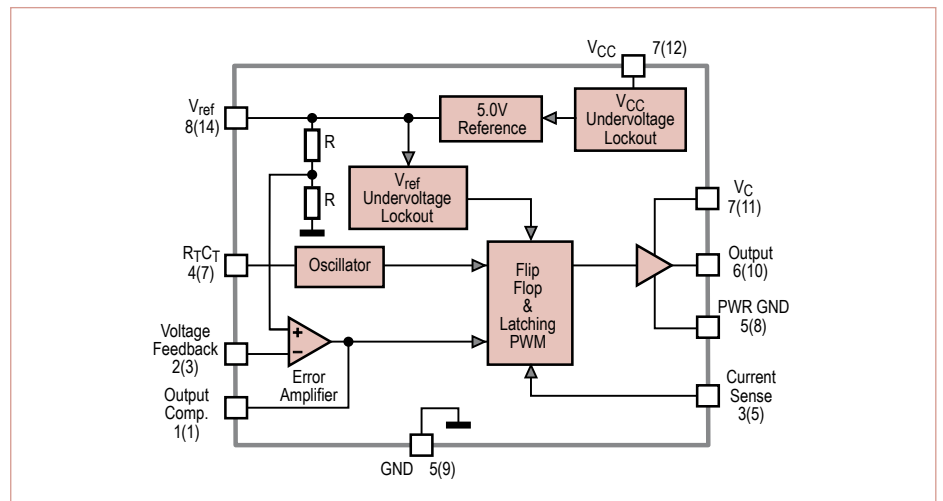


Figure 4. Inside the PWM generating IC.

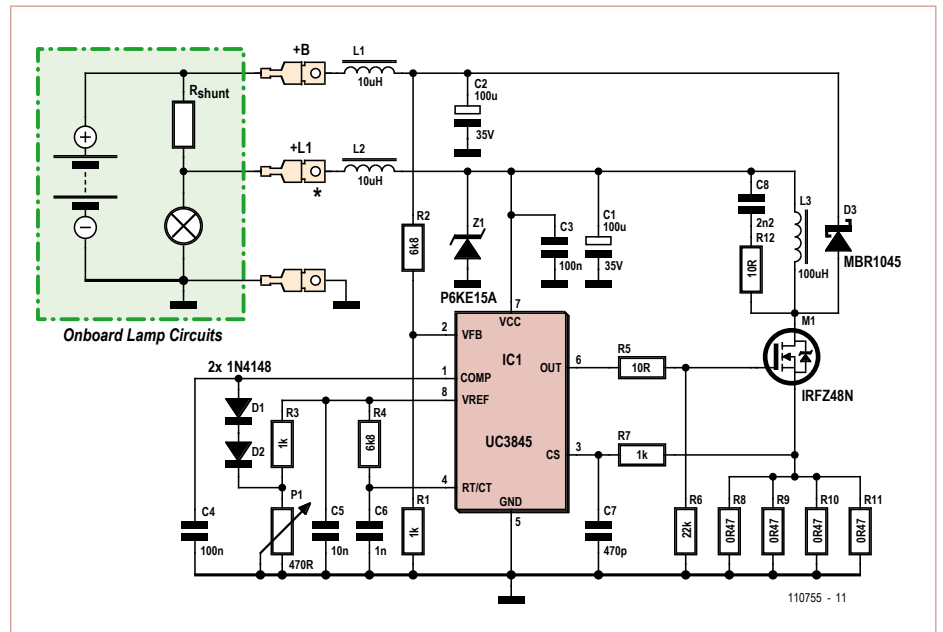


Figure 5. The full schematic shows our step-up converter based on the popular UC3845 PWM current mode controller.

ured at the current sense input, taking into account the error amplifier output. This happens in cyclic fashion. In our application the error amplifier is actually always saturated (High output), but this will be discussed below. The current set point is adjusted by clamping the Output compensation pin to the required level.

The clamping level is a constant voltage derived from a 5-V reference by voltage divider R_3/P_1 and temperature-compensated by diodes D_1 and D_2 . This way we implement a closed-loop control for the peak current with a setting point adjusta-

ble by P_1 .

You may have noticed voltage divider R_1/R_2 in Figure 5. It might look as if a voltage control loop is being closed, but the resistor values tell a different story. This is no more than an open-circuit protection. In normal operation the voltage at +B is limited to about 14V – even with engine running – so we get about 1.8 V at the feedback pin (pin 2), which compared to the 2.5 V reference at the non-inverting input will saturate the error amplifier as required. But if the controller kept regulating to a constant current and an open circuit fault would occur

COMPONENT LIST

Resistors

R1,R4 = 6.8k Ω
 R2,R3,R7 = 1k Ω
 R5,R12 = 10 Ω
 R6 = 22k Ω
 R8–R11 = 0.47 Ω 0.5W*
 R13 = 0.1 Ω 2W*
 * see text

Capacitors

C1,C2 = 100 μ F 35V, low ESR
 C3,C4 = 100nF
 C5 = 10nF
 C6 = 1nF
 C7 = 470pF
 C8 = 2.2nF

Inductors

L1,L2 = 10 μ H, 5A, Würth type 744711005 or
 Conrad Electronics # 420284
 L3 = 100 μ H, 5A, Würth type 7447070 or Con-
 rad Electronics # 438020

Semiconductors

D1,D2 = 1N4148
 D3 = MBR1045
 D4 = P6KE15A, TVS diode 15V 600W
 IC1 = UC3845N
 T1 = IRFZ48N

Miscellaneous

P1 = 470 Ω trimpot
 6.35 mm (0.25 in.) spade terminals for PCB
 mounting
 TO220 thermal insulator kit for D4 and T1
 Heatsink, 10K/W*
 PCB # 110755, www.elektorpcbservice.com
 * see text

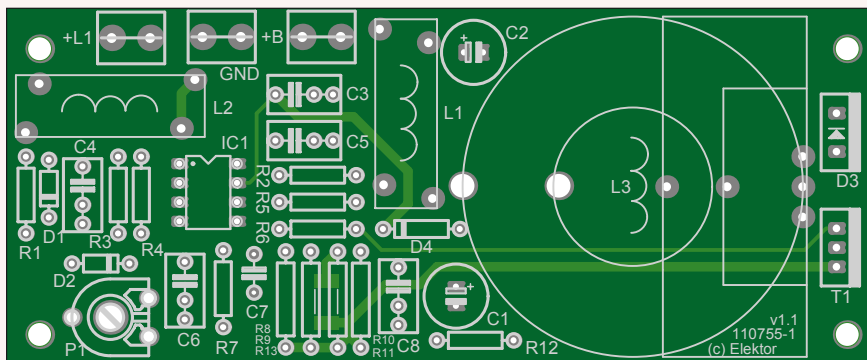


Figure 6. The PCB is designed to accept through-hole components, making soldering a breeze. One exception though: shunt resistors R8–R11 may be substituted by a single SMD resistor (R13).

at +B, there would be no way out for the energy stored in inductor L3, causing surges and possibly damage to components. Now the voltage feedback loop comes into play. Once the voltage at +B reaches about 19 V, the post error amplifier pulls down the current set point to a safe level. When working in constant-voltage mode C4 stabilises the feedback loop by slowing down its response. On a side note, under transient loads this is not a good voltage source, but it suffices in our application.

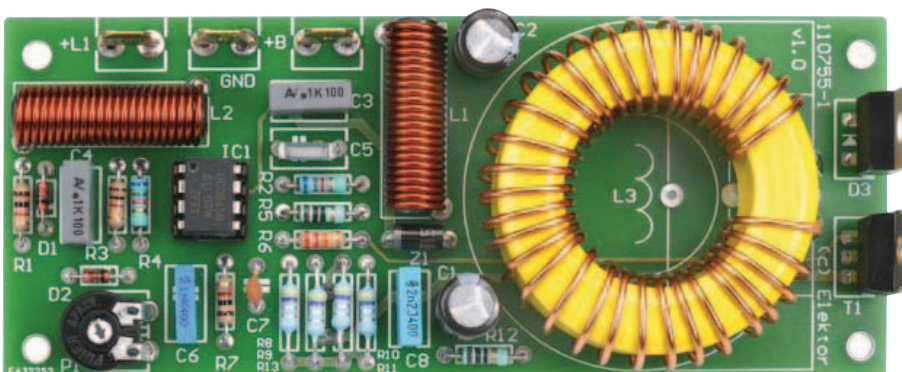
Schematics

The schematic in Figure 5 shows the complete circuit. Power arrives via terminal post +L1. Choke L2 smooths the current drawn by the circuit, keeping EMI in check, while transient voltage suppressor diode D4 eliminates voltage surges and spikes. Capacitor C1 provides the main power for the switcher stage. Its value is not very critical, but a good quality low ESR/ESL type is imperative. Moreover, as in any fast switching application, conventional capacitors usually fail rather quickly due to drying up of the electrolyte.

Next in line is the step-up stage consisting of L3, T1 and D3. Both the MOSFET and diode are conservatively specified, but cost little more while boosting reliability of the circuit. Safe operation requires a heatsink to be fitted when more than 1 A is sourced. D3 heats up quickest: the average current flowing through it is much larger than the current flowing through the MOSFET and the voltage drop across it is also larger even when using the specified Schottky diode. RC snubber network R12/C8 suppresses ringing due to stray capacitances on the MOSFET drain.

The current emanating from the cathode of D3 is buffered by C2 (apply the same considerations as for C1) and fed back into the battery through choke L1. Both C1 and C2 are a relatively low value with respect to similar switching applications, but in this circuit we are trying to kill those fast on/off transients, whilst the quality of the generated current is less important.

The PWM signal from controller IC1 is fed to the gate of the MOSFET via resistor R5. This resistor limits the peak current through the gate and attenuates ringing due to



stray inductance and gate capacitance. R6 is added to avoid a floating gate in case of an open circuit. The source current is passed through shunt resistors R8–R11/R13, generating a feedback voltage for the controller. Four parallel connected 0.5 watt resistors or a single 2512-shape SMT resistor are used instead of one common 2 watt resistor. The latter is mostly available as a wirewound type that cannot be used in this circuit in any case due its high stray inductance. The feedback voltage passes low-pass filter R7/C7 into the controller to avoid glitches that would impair its current regulation operation.

With R4/C6 the PWM switching frequency is set at around 100 kHz, which seems to be a good trade-off between smaller inductors and capacitors versus increasing switching losses and parts and PCB layout requirements. C5 filters the reference output. C4 does the same for the clamping voltage while also limiting the rising of the current set point, effectively providing a soft start function. C3, finally, buffers the IC supply voltage.

Construction and bench testing

Populating the PCB (Figure 6, layout available as a free download from [1]) is easy. As usual, start off mounting the low profile components and mind the orientation of the polarised ones, including electrolytic capacitors, diodes and the other semiconductors. Keep in mind the car is not a particularly friendly environment for any electronic device, so with the heavier components — especially the electrolytic capacitors and the inductors — it is safer to use a drop of silicone sealant on them. For mounting purposes two holes are conveniently provided to secure L3 to the board with a cable tie (when using the inductor from Conrad Electronics; see components list). After testing you may also want to protect the board with an electric grade lacquer (don't forget to mask the terminal posts and heat conducting surfaces of the diode and MOSFET with tape first).

None of the components are particularly critical. Nonetheless, think before you exchange or replace a component. Chokes L1 and L2 are not critical at all, any induc-

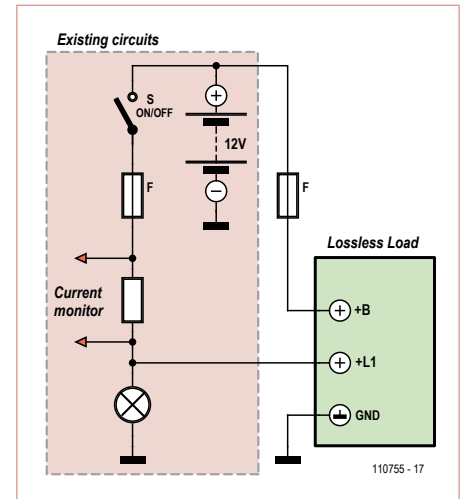
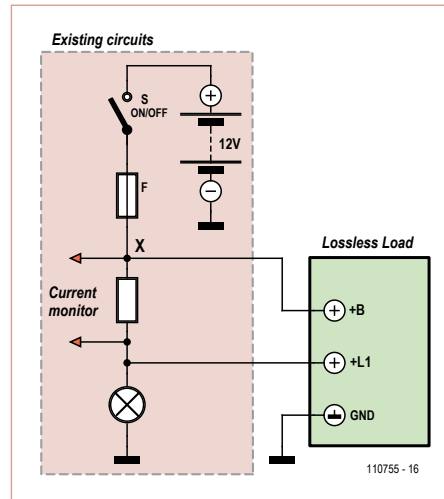


Figure 7 and 8. Connecting the Lossless Load into the car's circuitry can be done in the two ways as shown here.

tor capable of handling the rated current without saturating (too much) can be used safely. L3 can be bought ready made per the component list, but some experimentation with parts salvaged from similarly rated switching circuits may do the job too. Its inductance is not critical; just make sure it does not saturate at the current you wish to supply to the car's electric circuits.

A single heatsink may be used for all power semiconductors. This can be bought ready made, consisting of an L-shaped aluminium profile, approximately 30×30 mm (1.2×1.2 in), 2 mm (0.08 in) thick, or, in case you are using an aluminium housing, you may also use one of its walls as a heatsink. The power semiconductors are located along the PCB edge for ease of mounting a shared heatsink. Isolate the diode and the MOSFET from the heatsink using washers, since their metal tabs must not be connected to ground or shorted to each other. After careful inspection the board can be wired for bench testing. Connect a digital multimeter between +B and +L1 and set it to 10 A DC mode. Then connect a 13.8 V DC power supply to +B and GND. When using a battery or a power supply with no or a high current limit, also include a quick-blow 2 A fuse in series with the power supply for safety purposes. Switch on the power supply. Using P1 you should now be able to

smoothly adjust the current through the multimeter between almost zero and about 4 A.

Do not forget to monitor the diode and MOSFET temperature. Both components should not get so hot they can't be touched with a finger for quite some time. Otherwise, a bigger heatsink (or one with a lower K/W rating) should be used.

In case you want to measure the power losses — i.e. efficiency gained —, set P1 to the desired current, for example 2 A, then short circuit +B and +L1 with a wire, leaving everything else the same, and replace the fuse with the multimeter. If you are now seeing, say, 240 mA while supplying 2 A through the wire bridge, you're actually wasting a mere

$$13.8 \text{ V} \times 0.24 \text{ A} = 3.3 \text{ W}$$

instead of

$$13.8 \text{ V} \times 2 \text{ A} = 27.6 \text{ W}$$

that would be wasted in a simple bleeder resistor.

Installation and safety

It's a misconception to think that working on 'car electricals' is safer than working on AC powered devices. Sure, the voltages involved generally do not exceed 14 VDC,

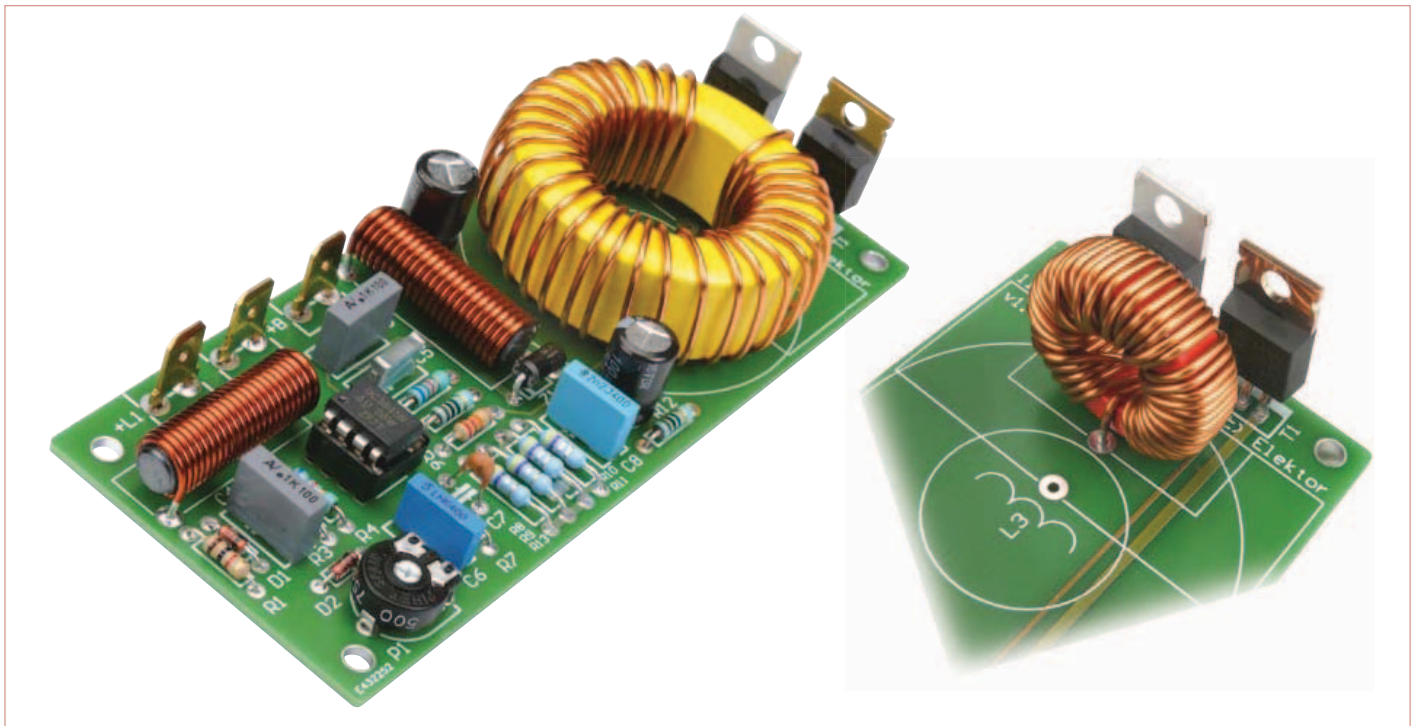


Figure 9. The PCB accepts different sizes of inductors. Shown on the right side is the relatively small 100 μ H coil from Würth Elektronik [2].

so indeed you may feel safe touching parts and wires. But then, a car battery is capable of supplying a few hundreds of amps in case of short circuit. Such currents are dangerous in that they can easily melt a binding post, a spanner or a screwdriver and project hot metal chunks and bits into your eyes or set fire to the whole wiring or even your beloved motor. Edd in *Wheeler Dealers* also issued similar warnings on TV. So the greatest possible care should be taken while installing and testing this circuit on-board! One of the diagrams shown in **Figures 7** and **8** may be used. The diagram in Figure 7 is probably the easiest. Both the +B and +L1 connections are protected by the existing fuse installed in the fuse compartment in or under the dashboard. The connection to the lamp can easily be made on the lamp holder proper, but it might prove rather difficult to physically reach point X without dismantling the whole car.

In Figure 8 the +L1 connection is still protected by the existing lamp fuse. A direct (unswitched) battery connection to +B could be tapped off somewhere, but it may

be easier to connect it directly on battery post. In this case — and whenever you are not sure protection is provided — an external fuse **MUST** be fitted. This could be one of those flying-lead car style fuseholders or a panel-style fuseholder mounted in the housing for the circuit. This fuse should be rated the same as the one in the dashboard. When everything is installed, we can now do our final adjustments and testing. First turn P1 to its minimum resistance, then power up the lamp circuit and slowly turn P1, increasing the supplied current until the lamp failure indicator goes out. Then turn P1 just a little more to avoid a setting too close to the threshold of the detection circuit. You may want to monitor the supplied current during this adjustment. To do so, wire a multimeter in series with the +L1 connection and set it to 10 A DC. Finally, you should check whether the failure monitor actually keeps working by removing the lamp. The current supplied by our circuit alone should **not** be enough to ‘cheat’ the monitoring circuit. If this were the case, the monitoring circuit would be of no use anymore. Make sure you double

check everything is working as expected, even with the engine running.

One last thing

Using a trimpot in this kind of application might be slightly less than ideal. Vibrations and other harsh environmental conditions could change the setting. A solution would be to use pinheaders to temporarily connect P1 during testing and adjusting. Then, after tuning your circuit, take out P1, measure its resistance and put in a fixed resistor with the same value instead. Now you can look forward to saving about 7 ml of fuel per hour for each 20 watts of electric power that’s not wasted as heat. Don’t do the sums while driving, though.

(110755)

Internet links:

- [1] www.elektor.com/110755
- [2] <http://www.we-online.de>

Note: Replacing car lights with non-approved aftermarket LED units may be in violation of local, national or state laws. Check local regulations before engaging in alterations on your car’s electronics.

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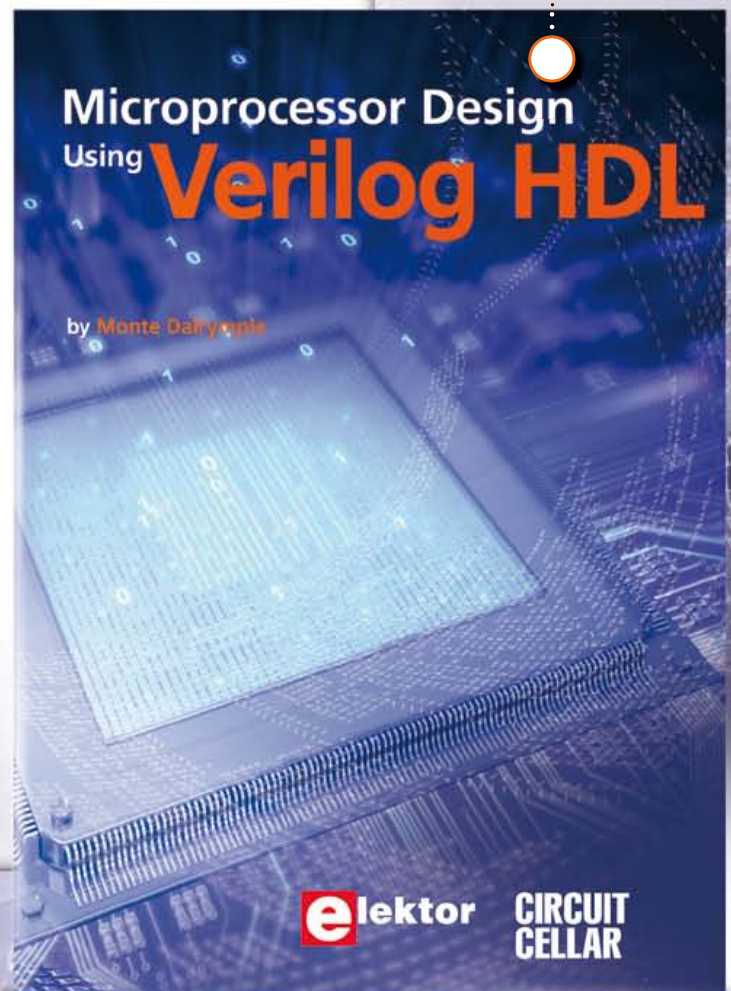
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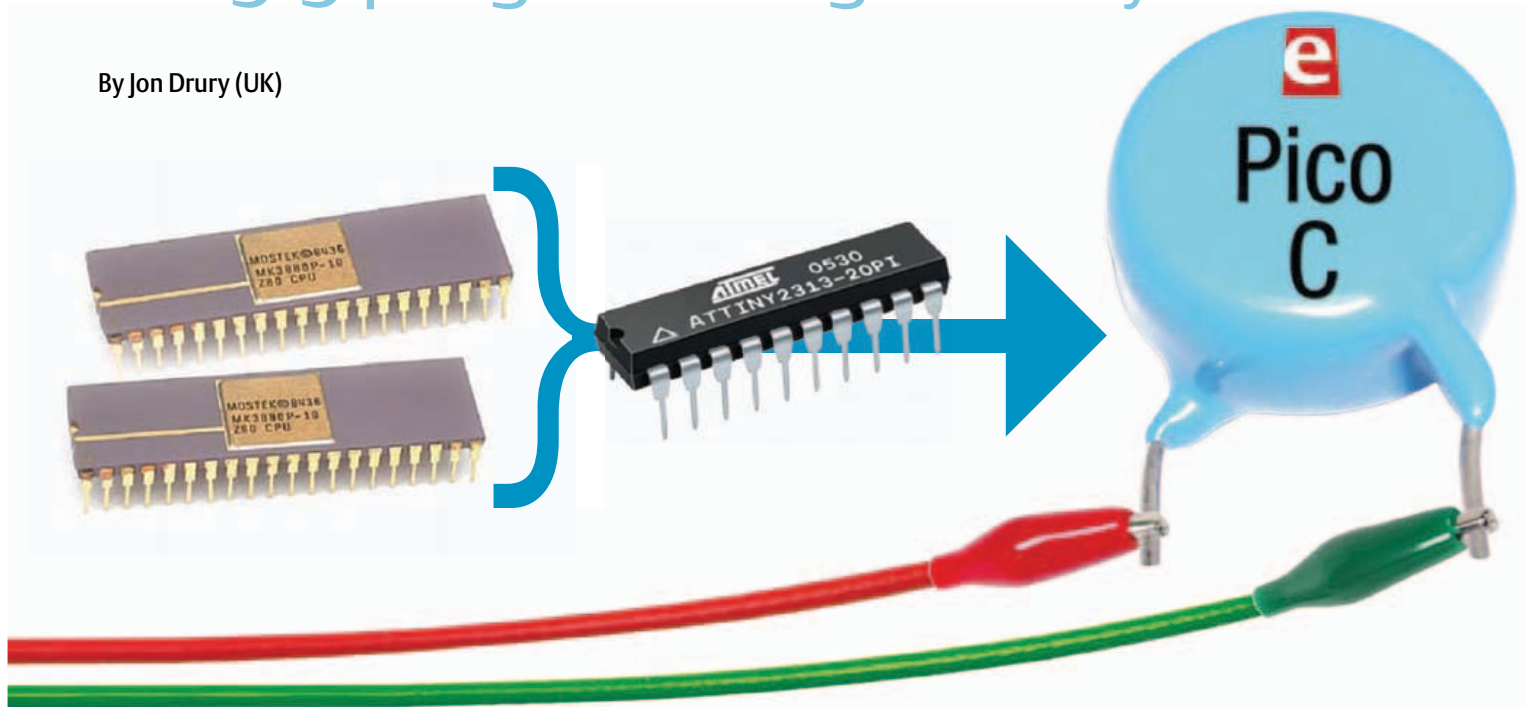
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Inside Pico C-Super

AT2313 programming Z80 style

By Jon Drury (UK)



Our recent Pico C-Plus & Pico C-Super publications went down very well with the Elektor crowd. At the request of many of you, in this afterburner article we delve into the software that makes the instrument tick, particularly the Plus version.

Graphologists will tell you a person's character from their handwriting. A programmer will tell you a person's history from their program code. When I first thought about extending the original Pico C code, I came to it with a background in small machines and many years of programming Z80 and similar. When I first started writing software you only got 512 bytes of program space if you were lucky, so I have been used to trying to squeeze a quart from a pint pot (or should it be one decilitre from a whole litre now). So when I read that it was a challenge to get the code for Pico C into an AT2313 microcontroller [1] and there were questionable limitations to the range, it felt like a challenge I should respond to. The result is Pico C-Super [2] — an extended version of the original idea with several extra functions crammed into the same extremely simple and low cost hardware through the use of software. In this article, I will try to explain how I did this and in the hope that others may find some of my code useful in their own projects in the same way that I have benefited from the wealth of code already available from Elektor and on the Internet.

Registers

Firstly, I want to talk about the use of registers briefly and this reflects my Z80 history. I find the Atmel notation of r0-r31 to be unhelpful and difficult to remember what is stored where. So it is easier to rename the registers with more useful names. In my case I rename them in

Z80 style with an 'A' register for general purpose use, a 'B' register for loop counting (anyone remember DJNZ — a.k.a. *Decrement, Jump Not Zero?*), and register pairs HL, DE, BC as 16 bit pairs for calculations. In the case of Pico C-Super there is a need for 24-bit arithmetic so I created a register triplet GHL as shown in **Listing 1**.

I keep all my Z80 registers in the range r16-31 as it's great to be able to use the immediate mode instructions like LDI, with the working registers. The lower registers (r0-15) I keep for variable storage as they are quicker to use than RAM. With Pico C-Super there is a need for 24 x 24 bit multiplication followed by 48 by 24 bit division. It makes the code more compact to have the result from the multiplication in a set of six registers (A0-5) which then directly become the dividend for the division subroutine.

Macros

It is useful to have some 16-bit Load instructions in the form of Macros as these are not included in the AVR instruction set. For example, the Macro LDIZ (see **Listing 2**) loads the Z register pair with a 16-bit value as a single program line. This Macro is replicated for the other 16 bit pairs BC, DE as well as X, and Y. There is also a Macro DJNZ to make me feel at home.

Assembler programming can become a little monotonous when you have to write the same set of code lines repeatedly but with different values included. The monotony can be relieved by writing

appropriate Macros or subroutines. As an example, Pico C-Super uses a Macro `WRNUM16` shown in **Listing 3**, to convert a binary number to decimal and do a formatted display on the LCD. This is just a single program line, but becomes several lines of assembler code when the program is compiled, which in turn call various subroutines. In these ways, the flexibility of the AVR registers and the Atmel Macro Assembler can be exploited to create a tailor-made environment to closely fit the application and so make the program both easier to write and more compact.

Interrupt service routine

The interrupt service routine or ISR shown in **Listing 4**, is the key to the period measurement function. Time is measured by using T0 and T1 concatenated to give a 24+ bit counter driven by the CPU clock running at 20 MHz. The interrupt mode is set for a rising edge so that the time interval between interrupts is equal to the period of the input at INT0. The ISR must start the timing process and stop it again after a pre-determined number of periods. It does this by counting the number of interrupts that have occurred using a variable `icnt`. This variable is set to zero in the main program before interrupts are enabled. This signals to the ISR that the next interrupt will start the count. The ISR then compares `icnt` with the number of periods to be measured using the register 'C' and stops the count when the target is reached, but still increments `icnt`. Meantime the main program is sitting in a tight loop which it cannot leave until `icnt` reaches the target+1 in register 'D'. Because the main program is not using any of the registers used by the ISR apart from the status register and `icnt`, the ISR only has to save and restore the status register. This ISR (`Int_sub`) is used for both interrupts on INT0 and INT1, which are used to measure external period and capacitance respectively.

The arithmetic routines used are written for 24 bits, so it is important to check that the count value does not exceed 24 bits or the arithmetic will go wrong. Overflow detection is not straight forward because the counter pair T0/T1 is 25 bits long as it includes OC0B. Overflow is checked by combining a conventional overflow ISR (`ovf_sub`) which tests bit 26, with a rotate and test carry for bit 25 in the routine `MeasB`. The main arithmetic routines are the 24 x 24 bit multiply and a 48 by 24 bit divide. These have

Listing 1. Part of register definition include file, creating Z80 look-alike registers.

```
.DEF    A=r16
.DEF    B=r20
.DEF    C=r21
.DEF    D=r22
.DEF    E=r23
.DEF    H=r24
.DEF    L=r25
.DEF    G=r28 ;this one is special for Pico Super
```

Listing 2. Examples of extensions to AVR instruction set.

```
.MACRO LDIZ    ;value to load
        LDI        ZH,high(@0)
        LDI        ZL,low(@0)
.ENDM

.MACRO DJNZ            ;Z80 decrement and jump not zero
        DEC        B
        BRNE    @0    ;jumps to label @0
.ENDM
```

Listing 3. Bin to dec conversion and number formatting for LCD.

```
.MACRO WRNUM16    ;position,predp,postdp. 16 bit variable in
HL
        RCALL    CNV5B        ;convert to BCD
        LDI        A,@0        ;LCD position
        LDI        B,@1        ;digits before decimal point
        LDI        C,@2        ;digits after decimal point
        RCALL    wrnumb        ;display it
.ENDM
```

Listing 4. Interrupt service routine for period measurement.

```
;Note 'C' is used to control number of Periods to be timed
Int_sub:    IN        A,SREG ;save SREG
            PUSH    A
            TST    icnt ;if icnt=0 use int to start count
            BREQ    i0strt
            CP        icnt,C ;else check for end of count
            BRCS    Int0x
            STOP_COUNT        ;is end of count
            RJMP    Int0x
i0strt:    NOP                    ;keeps start and stop
timing equal
            NOP
            START_COUNT        ;If icnt=0

Int0x: INC    icnt        ;bump count and exit
            POP    A        ;restore SREG
            OUT    SREG,A
            RETI
```

been derived from 16-bit versions from Atmel's note AVR200 and are binary versions of the long division and multiplication I learnt long ago at junior school. The Atmel divide routine needed some extra code to make it work correctly when the top bit of the divisor is set.

Tables

The software makes extensive use of tables particularly to set parameters in response to the multiplier selection but also to set up T1 in the signal generator mode and display the corresponding frequency. These tables are of the fixed record length variety so that a simple calculation can be used to find the start of a particular record (see `gtrecd`). Since ATtiny controllers don't include a `MULTIPLY` instruction, the calculation uses repetitive addition to do the multiplication. The structure of the records can be whatever is needed and it is only important to use them in the same way that they have been created. As an example the table in the EEPROM for setting the output frequency consists of 6 byte records. The first byte contains the prescaler bits for T1, the next two bytes contain the setting for OCR1, the next two are a binary value for the frequency to be shown on the LCD as decimal, and the last byte is the ASCII code for the units character displayed in front of the fixed text 'Hz'. The macro `GET_RECORD` makes the tables easier to access. Mode selection again uses a table which contains the address of the LCD message and the address of the program module that will be executed when the mode is selected. This provides a good opportunity to use the indirect jump instruction `JUMP` which is otherwise rarely used by me.

Subroutines

There is a style of writing subroutines that saves all the registers used on entry and restores them again on exit. I prefer not to bother with this within my subroutines, which keeps them more compact. As a consequence, I sometimes have to save and restore registers in the main program, but more often important variables are stored in SRAM or different registers can be chosen and the problems of register corruption avoided.

Classic/Super options

The program is designed to work with both the early ('classic') hardware configuration (board # 100823) and the modified one (board # 110687). The program uses conditional assembly to do this and the Boolean variable PB (first Published Board) is used to modify the program as required to work on the two different boards, and PB should be set correctly before compiling and programming chips. A second assembly option allows the larger ATtiny4313 micro to be used, which can provide additional frequency options for the signal generator mode.

Bonus

In the process of tidying up this program ready for publication of this article, I got rid of some code that was no longer needed and ended up with enough space to include one more function. This is a simple table driven pulse generator where the length of each pulse segment (High, Low) can be set in the range 1 to 64 μ s with 0.25 μ s

resolution and an arbitrary sequence length. The sequence then repeats. An example is shown in the screenshot in **Figure 1**. The table structure is explained in the source code (`ptab`). This function uses 8-bit numbers to set the segment length and whilst a 16-bit version would offer longer segment lengths, I suspect it would have lower resolution. To be investigated.

The source code now released on the Elektor website includes this extra function.

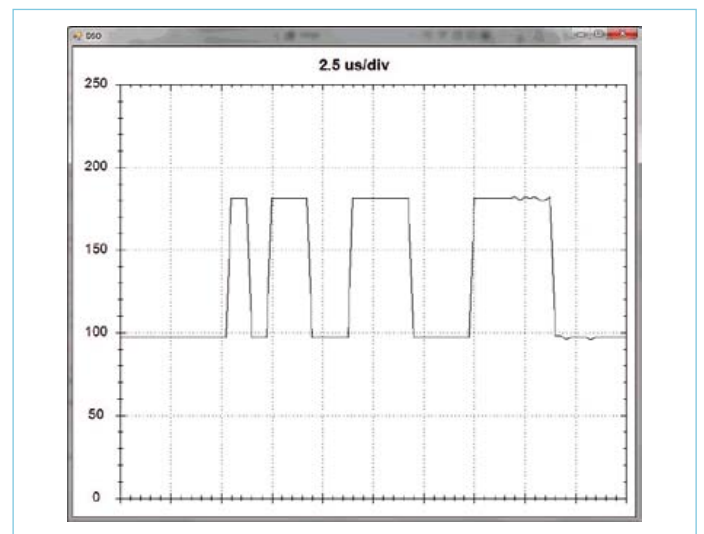


Figure 1. A 1-2-3-4- μ s pulse train shown on the Piccolo DSO at 4 Msa.

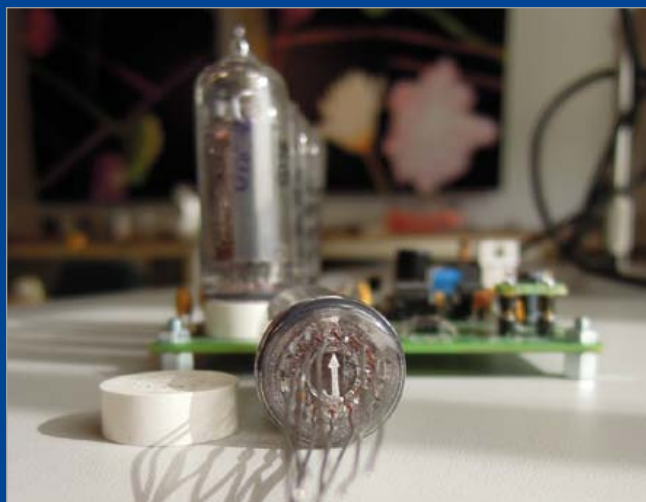
Compilation and AVR Studio 4

The program must have access to the Macro and Register definition files at compilation time, and these are included in the archive file # 110687-11.zip found on the Elektor website at [2] and [3]. The program has been written using Atmel's Studio 4 available free from their website [3]. Courier typeface has been used in this article text to indicate names and labels in the program code and these can easily be located in the program using the Edit>Find function in Studio 4. (120237)

References

- [1] Pico C,
Elektor April 2011.
www.elektor.com/100823
- [2] Pico C-Plus and Pico C-Super,
Elektor February 2012.
www.elektor.com/110687
- [3] www.elektor.com/120237
- [4] www.atmel.com/tools/AVRSTUDIO4.aspx

Mounting nixie tubes

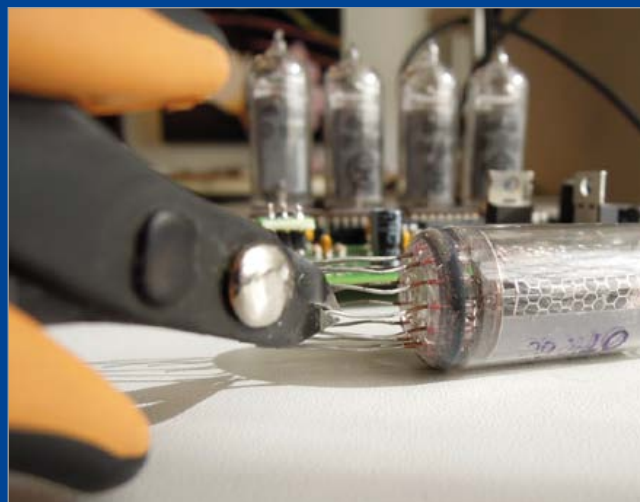


By Thijs Beckers (Elektor Editorial & Labs)

Coming up next month in Elektor Magazine — normally; hopefully — is a thermo/hygrometer project with Nixie Tubes. These vintage display tubes are making a comeback and projects using these famous tubes are popular as never before. Even Steve Wozniak carries them with him, or better: on him [1].

As customary with our projects, this Nixie Tube project was also replicated by the Elektor Labs. While assembling it, my fellow lab worker Luc Lemmens initially struggled a little when trying to get the tube leads through the PCB mounting holes. Have a look at the photographs to get an idea of the problem. After giving it some thought, he came up with an interesting solution we don't want to keep from you.

As the photographs tell, the cathode is marked by an arrow on the bottom of the glass envelope. So to begin with it would probably be helpful to mark the tube stand-off as well, so you still know the correct orientation when mounting the tube. A red dot works a treat and is not too conspicuous. Now for the



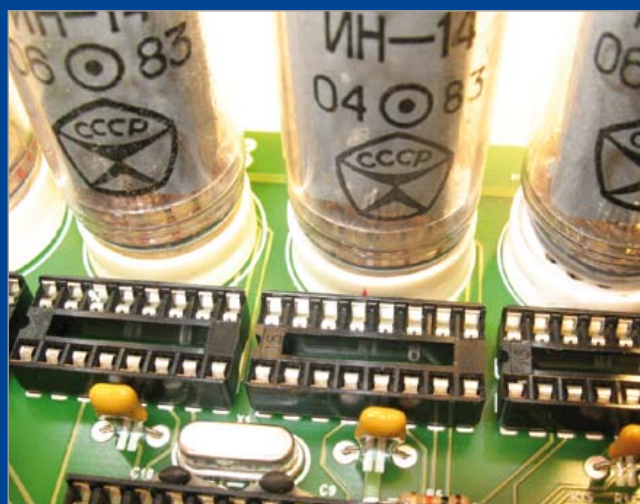
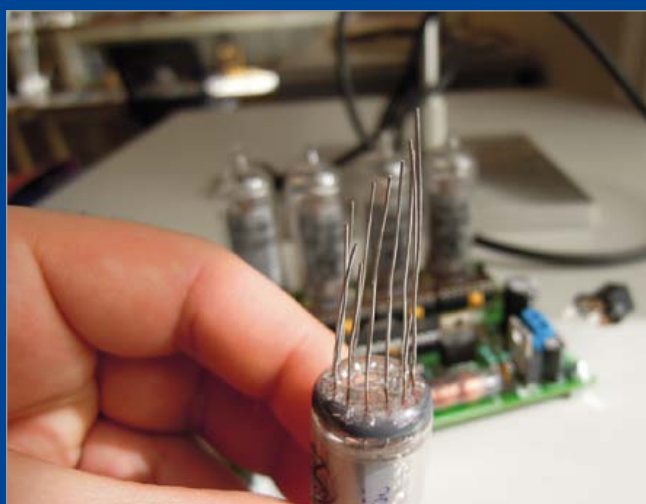
'more advanced' part.

Start with cutting one lead to about the correct length (not too short!) for the tube to be mounted on the PCB. If the tube leads are not inserted in the stand-off, don't forget to take into account the extra length required. Now cut the lead next to it (left or right, it doesn't matter as long you keep shifting in the same direction) but leave it a millimetre or so longer than the first one. Cut the next lead leaving another millimetre and so on. The end result should be that all leads have a different and clockwise increasing length (or decreasing, depending on how you look at it). The photographs show what the result should look like. This way it is much easier to guide the leads through the PCB pinholes and if needed also through the stand-off in one pass.

(120229)

Internet Link:

[1] <http://youtu.be/m4R3hODnTGo>



Quality check

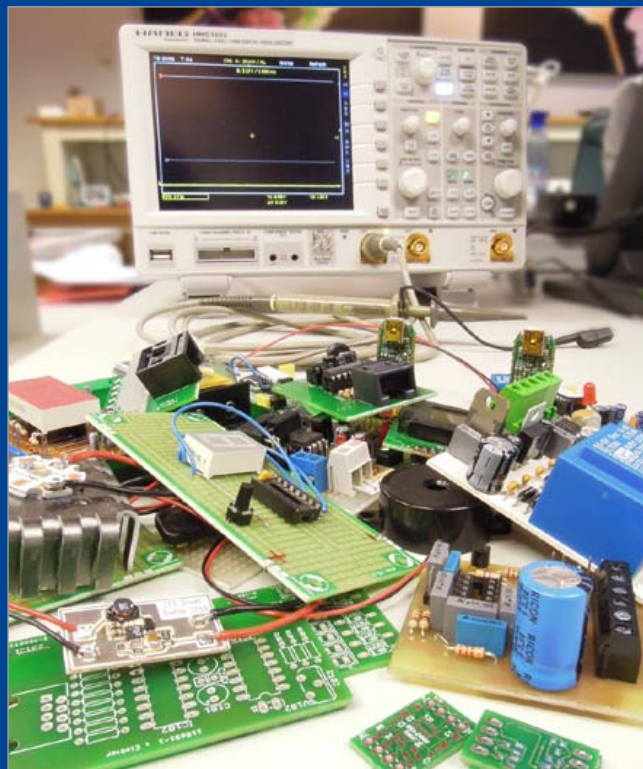
By Thijs Beckers (Elektor Editorial & Labs)

This year's July & August double edition of Elektor magazine will be somewhat different from the ones we produced over the past years. This year we pay extra attention to quality. We upped our standards and went through all the ideas, proposals and practical solutions in our IN box a second time to pick the ones we really liked. Only the top-notch of the cleverest of ideas that get past our first round of editorial filtering make it to this year's extra-thick magazine — the Project Generator Edition, PGE.

There is no reason to be apprehensive; the concept of this edition will not be not touched. You will still be able to pick up wagonloads of ideas and practical solutions from this most successful blockbuster edition. As a matter of fact, we will adjust our focus and elaborate on each and every circuit a lot more than we did in previous editions, aiming to leave no ends open and making sure every detail is crystal clear to all of you who digest this copy.

We know this will be a very ambitious goal for all of us here at Elektor as well as for our highly esteemed freelance contributors and experts, but it is all for the greater good — to serve and supply our community with fresh and exciting new project ideas, as well as keep the current flowing and the electrons kicking around.

(120305)



Transformer testing

By Raymond Vermeulen (Elektor Labs)

Elektor Labs are forever working on new projects and ideas. At the moment I am working on a USB isolating circuit. Besides isolating its data lines, it is also important to isolate its supply lines. Because the USB is DC powered, a traditional isolation transformer can not be used. I reverted to an isolated flyback converter instead. This solution also required a transformer, albeit a small one. The one I picked for the job goes by the arcane name 'part# 750310471' from manufacturer Würth Elektronik [1]. The photograph tells you a bit about its size.

This little transformer is production-tested for one second at 1850 volts. From this the manufacturer extrapolates that the device withstands 1500 volts for one minute continuously. The primary and secondary side are both shorted during this test so no current will flow through its windings. This confirms the isolation between the primary and secondary side.

That's nice & all, but what I'd really like to know is what happens when something goes wrong in a real situation. What if, for example, on one side the ground plane is shorted to the live wire resulting in the local AC powerline voltage continuously being superimposed on one side for hours and perhaps even

days? This hasn't been tested by the manufacturer (at least I didn't find it in the documentation), but I did need this information to be able to proceed with my project. So off to the test bench and hook it up!

Fused and connected using a variable autotransformer (Variac),



I replicated the manufacturer's test (with the two sides individually shorted) and left it for a couple of hours with 230 volts on its legs. It passed the test. Just to be sure, I then set up a second test in which the Variac was connected in such a way, that double the voltage was at my disposal. After a few hours at this higher than normal voltage and also passing this test successfully, I was convinced this transformer would suite my applica-

tion without any concerns and moved on to implementing it in my project.

(120302)

Internet Links

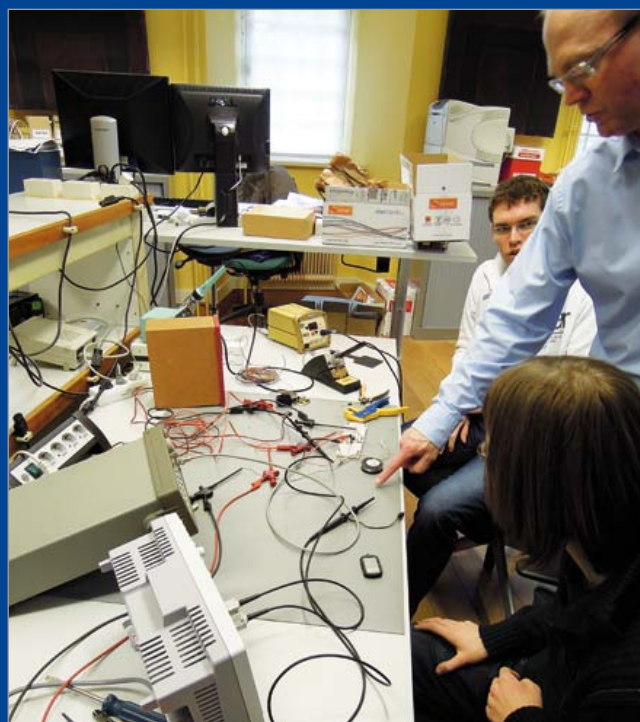
[1] www.we-online.de

Stray oscillations

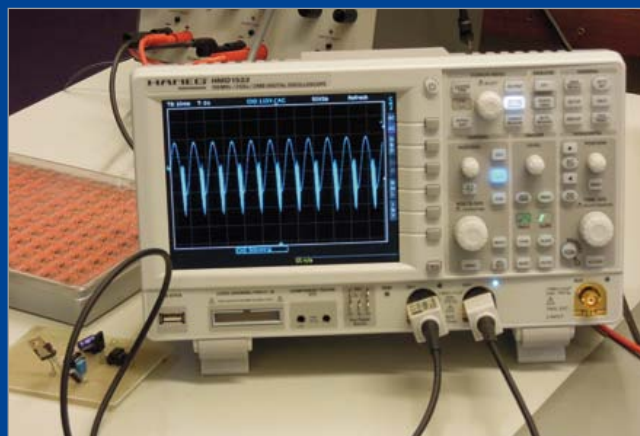
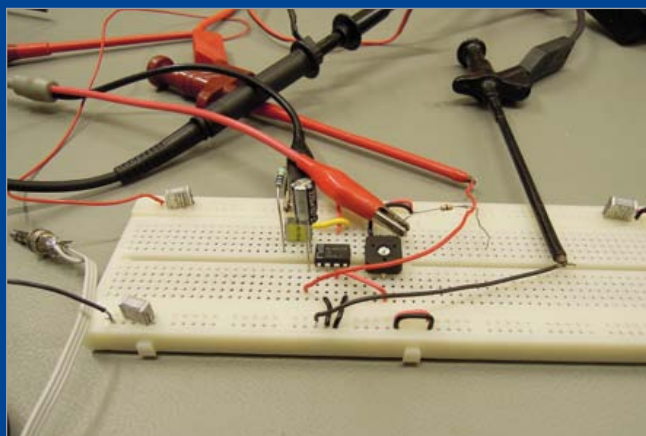
By Thijs Beckers (Elektor Editorial & Labs)

Many companies offer internships. There are several motives behind this established practice like providing a service to colleges and universities and improving educational standards, getting youngsters to do chores that are quite boring to senior designers but quite enlightening to interns, or educating potential employees who — by the time they finish their internships — are already familiar with the in house work flow, *et cetera*. Elektor at the moment also accommodates two interns in the Lab department, Koen Beckers and Jesper Raemaekers. Apart from their college projects, to which our designers provide assistance in times of need, they also work on circuits currently being prepared for publication in our July & August double edition. Koen & Jesper are even actively contributing ideas and circuits. This is one of them — and its design quirks.

The Line Out/Headphones Out signal from most laptop computers is rarely powerful. Driving a pair of rather power hungry headphones could end up clipping or overloading the output circuitry and sorely disappoint the listener. To overcome this inconvenience, a small external amp, preferably USB powered, might be considered. Now where to find something like that... That's when Koen's and Jesper's *electronic nerve* got triggered and they launched a small project of their own: a USB-stick-sized, LM386-based headphone amp. The first prototype, built up on breadboard, appeared to work. That is, until an oscilloscope was hooked up to take a closer look at the amplified signal, revealing a nasty issue with the little amplifier: wild oscillation.



Lucky for them, senior designer Ton Giesberts provided the answer. In his experience breadboards are not great solutions for prototype testing. They suffer from large amounts of stray capacitance between each row of connections, which in this



application invoked oscillation of the AF amplifier. His suggestion, to build up (exactly) the same circuit on a regular circuit board, paid off instantly. No more nasty oscillations and another circuit idea finished for our upcoming double edition! The crux: stay clearheaded with every decision you take regard-

ing your electronic endeavours, even if AF, and be weary of *Pico & The Strays*, they often perform unsolicited on the scope screen. And keep them circuits coming, guys!

(120334)

All the latest: LCR Meter

By Thijs Beckers (Elektor Editorial & Labs)

Just in! At the desk of fellow lab worker Antoine Authier colleagues gather round to get a glimpse of a cute LCR meter a French author submitted to Elektor “with a view to publication”. This neatly finished device is connected to a PC via USB. Specially developed software on the PC displays its measurement results. The meter employs the well established four-point measuring principle to get highly accurate measurements down to the lowest feasible & discernible level.

The test hooks are specially selected; each pin forms a

connection, so all you have to do is clamp them onto the component you want to check out and the instrument is able to perform a rather accurate analysis of the DUT.

Our initial tests looked very promising. This circuit is sure to be “evaluated for publication value” (as we call it) in Elektor magazine soon. Already the author is working on an extension to include an LCD so the instrument can be used in stand-alone mode.

...Can't wait to see this in publication!

(120331)



Piggybacking-1 k

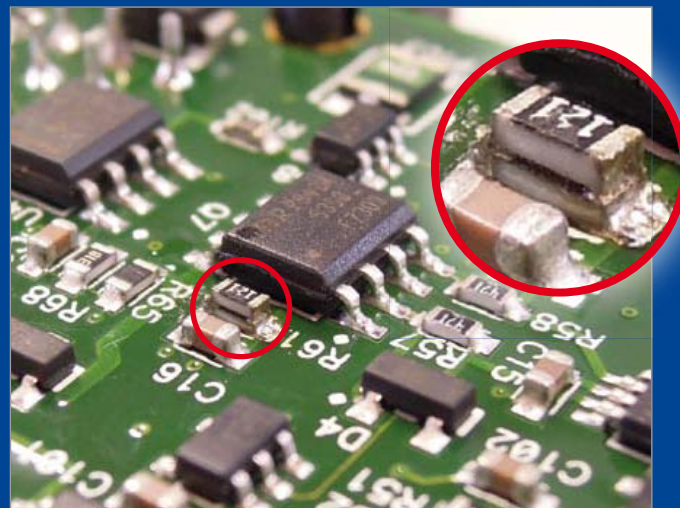
By Thijs Beckers (Elektor Editorial & Labs)

In this year's January edition of Elektor we discussed a couple of adjustments on Microchip's In Circuit Debugger 3 (ICD 3) (*Debugging the debugger*) in order to prevent a few issues when using the device. This called for desoldering two 1-k Ω SMD resistors and replacing them with 100- Ω types.

A kind & attentive Elektor reader from The Netherlands, Wim Sanders, tipped us off about an even easier way to complete this job: leave the 1-k Ω resistors in place and just solder the 100- Ω resistor on top of them. A “light backpack”, is what they call this at Sanders' daytime job. This piggybacking of 100 Ω onto 1 k Ω causes a mere 10% deviation of the required resistance, which in this case is not critical.

Thanks for the tip, Wim! Indeed, it confirms that adding is sometimes easier than replacing!

(120326)





What are you Doing?

Minty Geek's Mark Brickley

By Wisse Hettinga (Elektor UK/INT Editorial)

A keen observer of teeth during the day in his profession as a dentist, Mark Brickley stares at cells in the evening and gazes at stars at night. And yes, he is also looking into the future with his new projects dubbed Minty Geek. Time to put the question to him: “What are you Doing?”

“we are building a peppermint”

Wisse: What background?

Mark: I've always had a lot of interest in technology. From the earliest days I used to read Elektor and I made my first Z80 computer based on your publications, and then it went on and on.

Wisse: “On and on” means that Mark holds two Ph.D.s (one on Neural Networks and one on the electrical/mitochondrial signals in green algae) — he established his own research laboratory in the middle of Somerset and combines it all with an orthodontic practice.

Mark: I can do with little sleep, he explains when asked where he is finding time to do it all.

Wisse: The reason for this interview is the ‘Minty Geek’ product line you and your team are producing and selling through Elektor [1]. Whence the drive?

Mark: I believe there is an enormous value in making things. Young people have to experience that and the Minty Geek line of products is aiming at that group.

Wisse: We've seen different types of Minty Geek products; you have the 101 Lab allowing you to do some interesting experiments without soldering and there appear to be new products in the pipeline.

Mark: Our next product aims at people wanting to have a go at microcontrollers. We are building a ‘Peppermint’ which allows

for an ‘Arduino-in-a-Box’ capable of communicating with the 101 Lab Box for example. In this way it will be possible to interconnect Minty's. Also, we are looking at new ways to integrate electronics and clothes.



Wisse: Is there something left on your wish list?

Mark (jokingly): Sure, one day I would like to build a Hadron Collider! (more serious) I think we are entering a new phase in history where producing products is not longer the exclusive realm of the big companies, because with 3-D printers consumers will be able to print their own products”.

Wisse: Now, that Hadron Collider is perhaps pushing it too much, but having said that I wouldn't be surprised to hear about a huge experimental ring somewhere in Somerset in 10

years' time — possibly looking like the largest ‘Life Saver’ sweet ever made [2], with you in the middle.

Thanks Mark — good luck!

(120333)

Internet Links

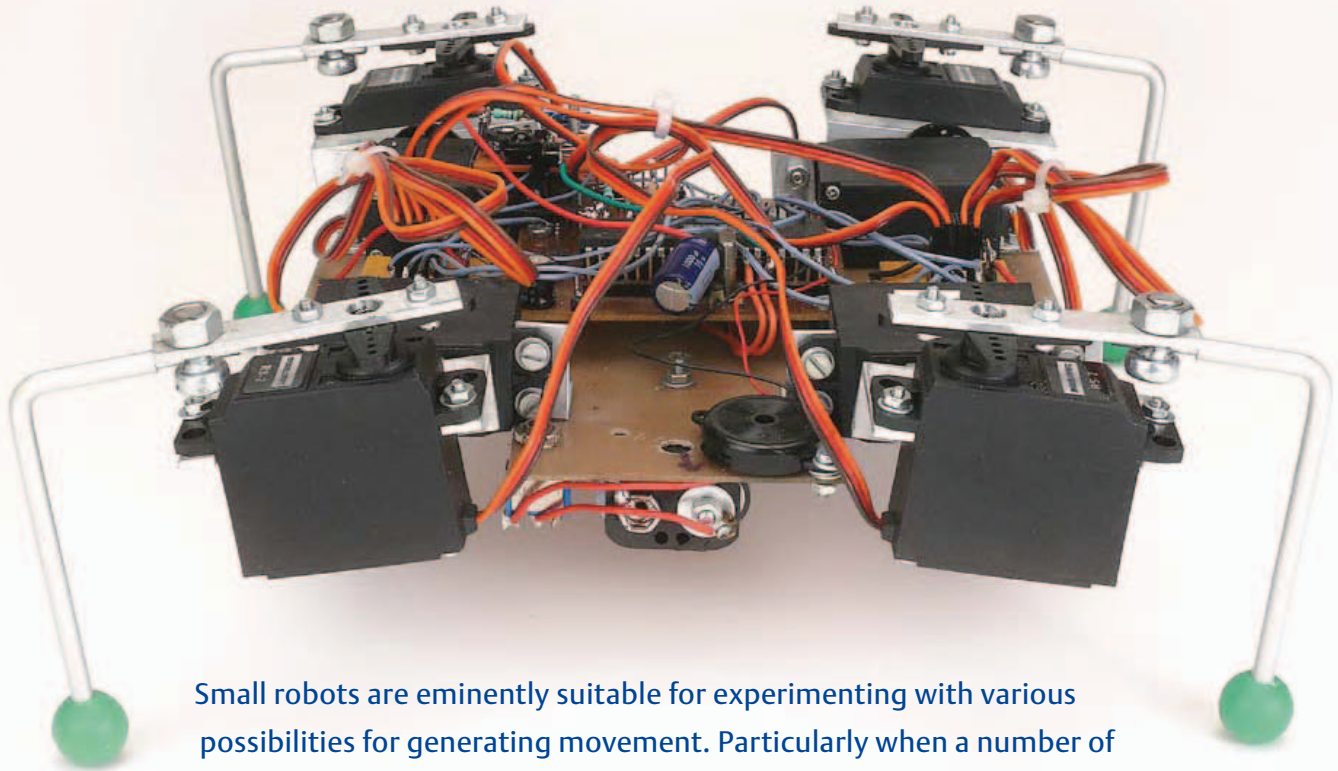
[1] www.elektor.com; search: Minty Geek

[2] http://en.wikipedia.org/wiki/Life_Savers

“I can do with little sleep”

QuadroWalker

Small four-legged robot with eight servos



Small robots are eminently suitable for experimenting with various possibilities for generating movement. Particularly when a number of legs are used, the designer has many options for the method of locomotion that the robot could use. Our QuadroWalker has a very simple construction using four legs, which anyone can easily build for themselves. The robot receives commands from a standard IR-remote control.

By Gert Baars (The Netherlands)

The concept of a robot is usually understood to be a programmable machine that's designed to carry out specific tasks. Examples of these are welding robots in car factories, which weld car parts together along a conveyor belt and are always moving at the same speed and are invariably making the exact same movements to yield a consistent quality. There are also robots which got developed to look as much as possible like a human, both in appearance and in functionality. A famous example of this is the ASIMO robot developed by Honda.

The closest resemblance of the robot described here is that to an animal, because it walks on four legs. A number of methods of locomotion were examined before arriving at this concept. A spider, for example,

has six legs and can always have at least three legs on the ground for balance. To ensure that the construction does not become overcomplicated, the preference here is for using four legs only. The robot does not have an organ of balance, in the form of a gyroscope or accelerometer, as they are often implemented. With four legs there is the option of a method of locomotion that contains a moment of imbalance, but by making the step size not too high and the step time not too long, this duration of imbalance is short enough to make walking possible. There are animals which actually do the same thing, but these often have a low centre of gravity, such as lizards. In this robot the centre of gravity has been kept as low as possible too, and most of the weight (the batteryholder with batteries) is located on the underside.

Before even starting a design like that, it is

necessary to check first whether it is even possible. From studying several methods of locomotion, it appears that a leg is suitable provided that it can move around at least two axes, and where these axes of movement are at the top of the leg. This eliminates the necessity for a knee or ankle joint. In this way a kind of ball joint is created, which allows two simultaneous movements, such a lifting and repositioning of a leg. Single axis movements can be realised nicely using servos. With a servo the angle of rotation can be set, and therefore also the amount of movement. In this case, each leg requires two servos, so as a consequence there are a total of eight servos.

Design

The design of the robot can be divided into three parts: mechanical, electronics and software. The mechanical part takes care

of attaching the base plate to the legs via the servos. The servos also have to be joined together. This requires the manufacture of a few mounting brackets, two right-angle brackets for four servos to attach them to the base plate. Also, for each pair of servos a bracket to allow them to move at right angles with respect to each other (this kind of bracket is available for sale for certain types of servos) and a bracket to attach the leg to the second servo. The materials used here are aluminium angle extrusion and flat bar material, which have to be cut to the correct size and require the drilling of a few holes. **Figure 1** gives an indication of how all this can be achieved. There are obviously other ways of doing this. The legs of the prototype are made from 4 mm aluminium round rod. These can be fastened to the servo bracket by drilling a 4 mm hole in a bolt so that it forms a clamp, but 4 mm U-bolts are often also available from hardware supply stores and these would also be suitable. The amount of horizontal length from the 90 degree bend in the legs must not be more than what is necessary to allow unrestricted movement going forwards and backwards, and vertically keep the centre of gravity as low as possible so that there is just a small margin between the bottom of the robot and the floor while walking.

The particular choice of the servos that have been used, depends on the force that they have to deliver. These are specified as a torque in kilograms times meters. Because two legs can be off the ground while walking, each of the servos that's connected to the base plate has to be able to support half of the total weight. The weight of the prototype, including the batteries, amounts to about 750 grams (26.5 oz.). The horizontal length of the legs is 6 cm (4 inches). The torque then amounts to 2.1 kgf.cm (1.82 lbf.in). Servos of the type RS-2, a commonly used, readily available and affordable servo can supply over 4 kg.cm (3.47 lbf.in) at 5 volts and is therefore very suitable for this robot. The horizontal length of the legs determines the torque, so it is not possible to just change this. Also, the current consumption is proportional to the torque supplied; placing the legs closer to the body therefore also means that the batteries will last longer. **Figure 2** shows how the robot

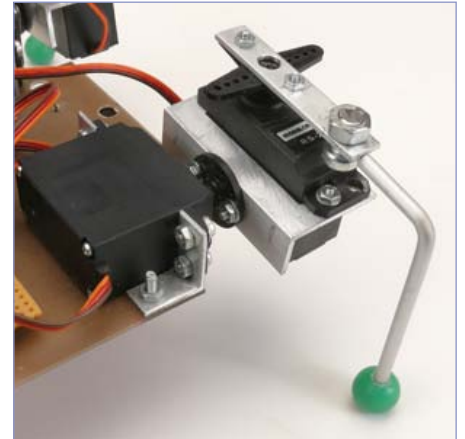
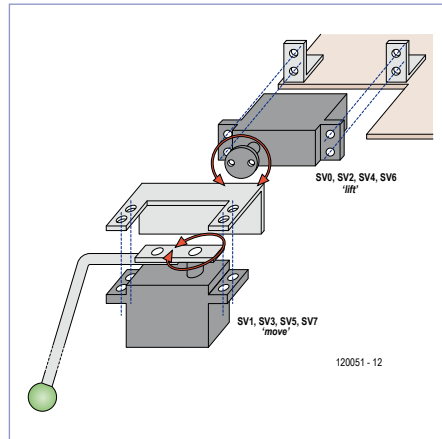


Figure 1. The servos are attached with the aid of a few pieces of angle bracket.

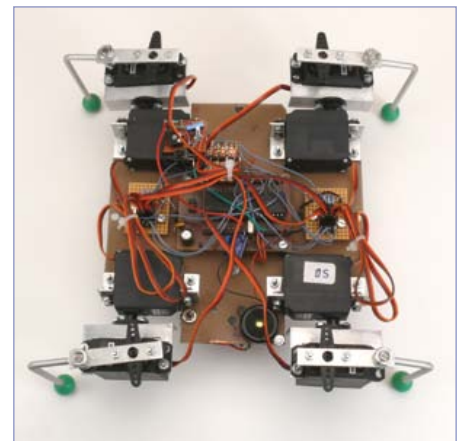
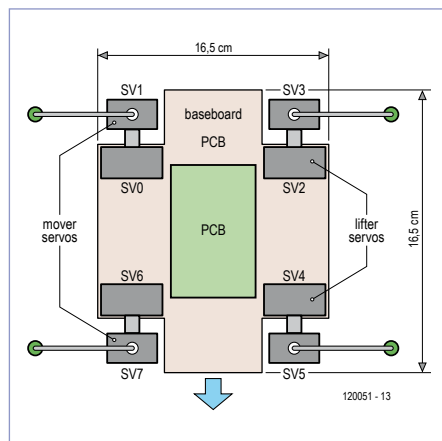


Figure 2. Design of the robot and positioning of the servos.

is put together. The base plate of the prototype consists of a piece of circuit board with the eight servos mounted on the four corners, in the middle, on top is the circuit board with the controller, and the RC5 IR-sensor is pointing upwards for a maximum range of the remote control of several meters. The battery holder is attached to the underside, note that this should be positioned reasonably well in the centre, keeping in mind the centre of gravity.

Electronics

In the hardware, the servo control and the other functions are taken care of by a

microcontroller. Not all that many I/O lines are required, but the author already had a small board containing an ATmega32, so that got used here (see **Figure 3**). Because the controller has a large program memory, the robot can easily be expanded with many other features. Eight outputs from the controller supply the pulsewidth-modulated signals for the servos, so that each servo can be controlled individually. An interrupt input reads the data that is received by the RC5 sensor, in this way a standard RC5 compatible remote control can be used to control the robot from a distance. The motor currents of the four servos control-

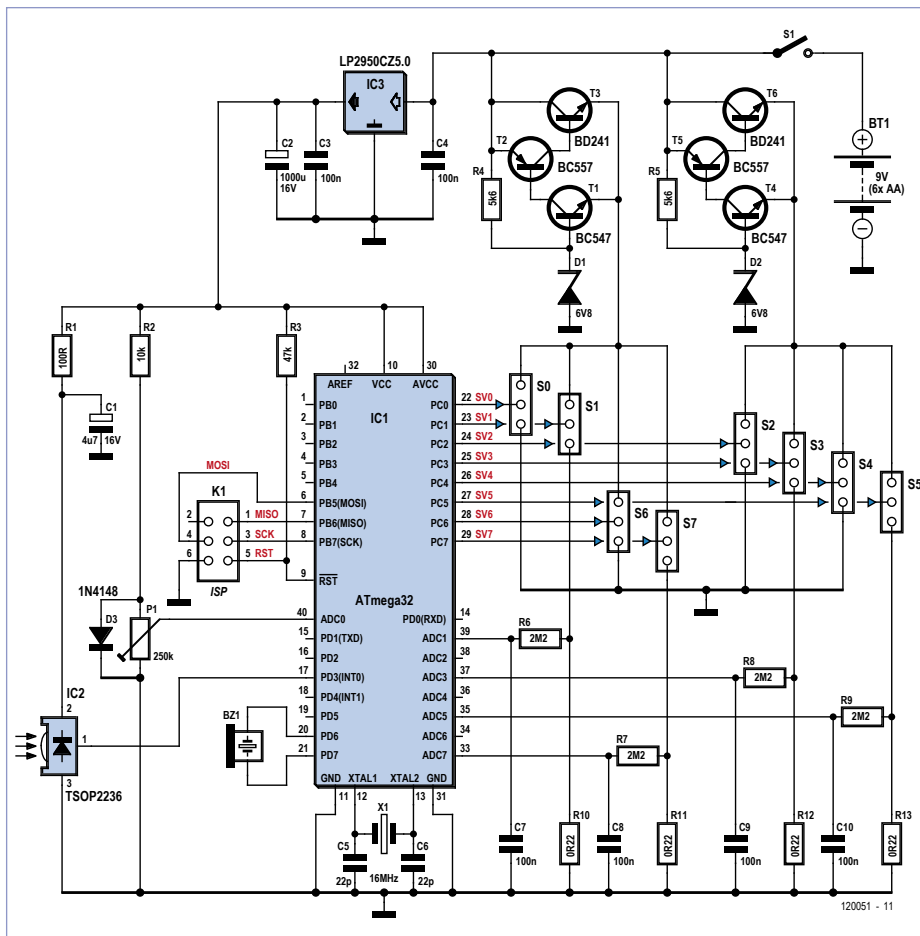


Figure 3. The electronics comprises mainly of an ATmega32. Two voltage regulators, made from discretes, take care of the power supply for the servos.

ling the horizontal movement of the legs are available as voltages, using resistors in the ground wires. This is not a constant voltage because the motor in a servo is controlled digitally. That is why lowpass filters are added, which smooth the voltage waveform. These can then be measured via the ADC inputs, with the objective of detecting when the robot is impeded in its movement. In this way it is possible to detect obstacles so that the robot may avoid them. This is also the only intelligence that the robot possesses, but it is sufficient to allow it to be called 'autonomous'. The current at which an obstacle is detected can be set with a potentiometer on an additional ADC input (ADC0), which is used by the software as a reference. This threshold depends also on the friction between the legs and the surface underneath.

In the prototype, small hard plastic balls were attached to the end of the legs to prevent scratches, but at the same time also minimises the friction with the walking surface. This works well on a wooden floor, and also on vinyl and carpet, because the

motor currents remain relatively small in the absence of an obstacle. When rubber feet are used there is so much friction that it becomes difficult to find a good position for the potentiometer to reliably detect an obstacle.

The servos require a power supply voltage of 4.8 to 6 V. Using four AA-batteries, resulting in 6 V, would be perfect without requiring any further regulation, but the voltage does drop considerably when the batteries discharge. That is why six AA-batteries are used, which means that voltage regulators are now required to ensure that the voltage does not exceed 6 V. Many ICs are available for this purpose, but the preference goes to regulators with a low voltage drop, to obtain maximum life from the batteries. A cheap solution turns out to be two simple discrete regulators with less than 1 V voltage drop, consisting of a few transistors and a Zener diode. Two regulators are used here, not only so that the voltage drop is minimised, but also because this avoids the need for a heatsink.

Software

The software is written in assembler and consists mainly of a few interrupt routines. For example, it is important that the servos receive a pulse with a duration of 1 to 2 ms every 20 ms. Deviating from this results in vibration in the legs. The TSOP2236 IR receiver also has to be read using a hardware interrupt, because here the timing has to be exact as well. In the software, the control of the eight servos is spread across the period of 20 ms. If all the servos were to be controlled simultaneously this would result in an undesirably large peak in the battery current.

The control of the servo positions is derived from a sine lookup table which contains 256 values between 0 and 100, corresponding to the 1 ms control range divided into steps of 10 μ s. By controlling the two servos of each leg with a phase difference between the sine waves it is possible to move the leg joint in a circular or elliptical motion. This is desirable because it allows steps to be taken in which a leg can be lifted and moved forwards simultaneously, or lowered and moved backwards. This corresponds sufficiently to a walking motion.

All eight servos are now controlled with phase differences in such a way that two main ways of walking are possible: forwards and backwards, which for the latter case is just a matter of reversing the phase, but also turning to allow a change of direction. The values of the phases for these two basic movements are also stored in a table, eight values for each movement, where each value is the phase difference for a servo. It should also be possible to turn both to the left and to the right, which again is also a case of phase reversal.

The function of this robot is, in principle, only moving around and being controlled on command from the infrared remote control. But additionally, with a certain command the obstacle detection can be turned on and off. When this is the case, the motor current as measured by the ADC inputs is compared with the value from the potentiometer; when this is exceeded four actions are taken. Firstly, the loudspeaker emits a signal and the robot stops. Subsequently, it will walk several steps backwards. After that, the robot turns a number of degrees,

Table 1. Commands available via RC5 remote control	
1	kick left front leg
2	move forward
3	kick right front leg
4	turn left
5	halt
6	turn right
7	kick left rear leg
8	move backward
9	kick right rear leg
mute X	'Function'
volume +	speed up, servo6 up
volume -	speed down, servo6 down
brightness +	stepsize up
brightness -	stepsize down
colour saturation +	stepheight up
colour saturation -	stepheight down
treble +	spider height up
treble -	spider height down

where the direction depends on which leg detected the obstacle and in such way that it turns away from the obstacle. Now the robot stops again and then continues on its way. In this way the robot can continue to walk without any help from the outside. If it walks into a wall, for example, it will continually move away from this and continue on forever, well for as long as the batteries allow anyway.

To study whether a robot of this type is also suitable to play soccer, for example, an additional function is built in which allows one leg to make a kicking movement. With this, the diagonally opposite leg is also lifted briefly as a counter movement for improved balance. The result is that the robot can kick a ping-pong ball about a metre away, which can offer interesting possibilities, provided the playing field is not too large. It is, of course, also possible to expand the robot with, for example, a kind of electro-magnet which is sometimes used in special soccer playing robots.

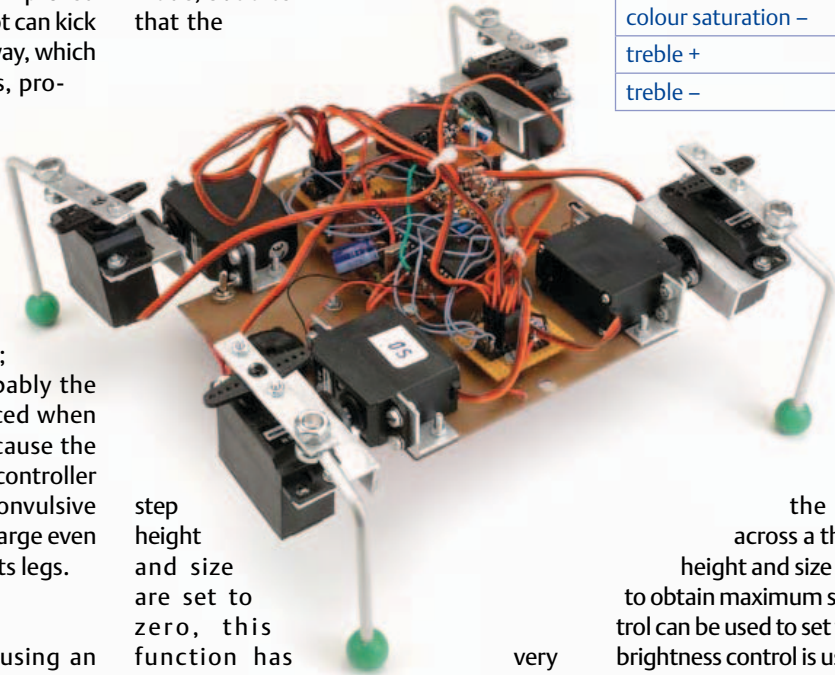
Battery life is strongly dependent on the activities of the robot; rechargeable batteries are probably the best choice here. It can be noticed when the batteries are nearly flat, because the brown-out function of the microcontroller will operate, which results in a convulsive motion. When the batteries discharge even further the robot will just sag on its legs.

Remote control

Controlling the robot is done using an RC5-compatible TV-remote control. In the software the first byte of the RC5-code is ignored, which means that other types may be usable as well. This can be changed, of course, so that multiple robots can be controlled independently of each other. The commands are straight ahead, reverse, turn left and right. By using the mute-button (loudspeaker symbol) on the remote control additional functions are available, for example to turn obstacle detection on and off, and also another function for balancing the robot. This last function allows a vertical offset to be added to servo6 of the front-right leg, so that in the initial state

all four legs touch the ground at the same time. Because of mechanical variations it is possible that one leg is too high or too low, which makes walking more difficult. After making the adjustment, the value of this offset is stored in the internal EEPROM of the controller, so that it is used again on next power on.

Table 1 shows an overview of the available commands. The buttons 1 through 9 are for the normal control. The mute-button is used as a function-key and has to be followed by a number. With these, function-1: obstacle detection on/off, with function-2 a kind of tilt movement can be made, but after that the



step height and size are set to zero, this function has very little use otherwise and is really only for testing. With function-9 the offset of the height of servo number 6 can be adjusted and is stored in EEPROM. This should be a once-only adjustment to set the balance. To make this adjustment, turn the robot on and push [function][9]. Support the robot with one hand underneath and push the button [volume+] a few times. Servo number 6 will now go up. Lift the robot so that all legs, except servo number 6, just touch the ground. Now push [volume-] until the leg of servo number 6 also just touches the ground. Push [function][9] again and the settings are

stored. While walking, the walking behaviour can be adjusted with the volume-, brightness-, colour- and treble-buttons as shown in the table. If, for example,

the robot needs to step across a threshold then the step height and size can be increased. Also to obtain maximum speed, the volume control can be used to set the step speed and the brightness control is used to set the step size. On a slippery surface it is sometimes better to use slow, large steps, while on carpet the walking goes better with faster, large steps. During tests a maximum speed of about 1 km/hour (0.63 mile/hr) was measured. The assembly and hex code for this project are available on the accompanying web page [1]. In the video of [2] you can see the robot in action.

(120051)

Internet Links

- [1] www.elektor.com/120051
- [2] www.youtube.com/watch?v=8ToHa4hQi_0

Electronics for Starters (5)

Voltage stabilisation

In the previous instalment of this course series we looked at circuits for constant-current sources. Now it's time to examine ways to generate stable voltages. Of course, you can always use an integrated voltage regulator, but there are many other interesting approaches, most of which need only a few (usually discrete) components.

By Burkhard Kainka (Germany)

If you carefully inspect the many schematic diagrams published in Elektor magazine, you will repeatedly encounter voltage stabilisation circuits. Some devices are powered by batteries, and the output voltages of batteries can vary over a relatively wide range. For this reason, a voltage regulator is often used in such devices to provide a somewhat lower but stable voltage, such as 5 V for digital circuitry or a microcontroller.

Diode stabilisation

Voltage stabilisation is not a difficult issue in practice, since wonderful voltage regulator ICs such as the 7805 are readily available. Operating from an input voltage anywhere between 7 V and 30 V, it supplies an output voltage of exactly 5 V. However, this IC contains a large number of components. You can manage with a single semiconductor device instead, namely a Zener diode. The 7805 actually contains a Zener diode, along with lots of transistors. A Zener diode is a type of diode in which breakdown occurs at a well-defined reverse voltage. For instance, you can buy a Zener diode with a rated voltage of 6.8 V if you want to stabilise a supply voltage at this value. **Figure 1** shows the corresponding basic circuit.

The operating principle of this circuit can be seen from the characteristic curve of a typical Zener diode (**Figure 2**). First breakdown occurs when the reverse voltage rises above a certain value (U_Z), leading to a sharp increase in the reverse current. The voltage across the diode remains stable at the breakdown voltage, as long as you don't overdo it with the reverse current. Second breakdown is a frequently observed fault with Zener diodes. If the Zener diode becomes too hot, the junction shorts out, and after this the diode 'stabilises' the volt-

age at something close to zero volts.

Strictly speaking, the designation 'Zener diode' is not always correct, because two different phenomena are responsible for the breakdown effect with voltages over the range of 3 V to 200 V. The true Zener effect predominates at voltages below 5.6 V. It has a negative temperature coefficient, causing the Zener voltage to drop by up to 0.1% per degree. The avalanche effect, which predominates above 5.6 V, has a positive temperature coefficient. Zener diodes with a rated voltage of 5.1 V have the lowest temperature coefficient, while Zener diodes rated at 7.5 V or so have the steepest characteristic curves and therefore the lowest differential internal resistance. This means that they provide the best voltage stabilisation with variable Zener current.

Quick solution

Sometimes all you need is a more or less stable voltage in the range of 2 to 3 V, with relatively little current. For example, you may want to power the RF front end stages of a simple radio circuit from a low voltage, while the output amplifier operates directly from a 9 V battery. In such cases you can use

a forward-biased LED as a simple voltage stabiliser (**Figure 3**).

The base-emitter junction of a perfectly ordinary NPN transistor has the same characteristics as a Zener diode. The Zener voltage is usually somewhere in the range of 7 to 12 V. The value with a BC547B is approximately 9 V, which lies in the favourable range with very low internal resistance. This type of transistor can therefore be used quite nicely as a Zener diode, although the exact Zener voltage cannot be known in advance. The manufacturers' data sheets don't say anything about this, although they do state that the reverse breakdown voltage of the base-emitter junction is at least 5 V. Here first breakdown of the base-emitter junction is a sort of useful side-effect. If you don't have a Zener diode handy, you may be able to make do with a transistor (**Figure 4**). Try it for yourself: apply reverse voltage to the base-emitter junctions of a few transistors and measure their Zener voltages.

By the way, there's another little-known side effect: the 'Zener diode' of an NPN transistor emits yellow light. If you try this experiment with a transistor in a metal

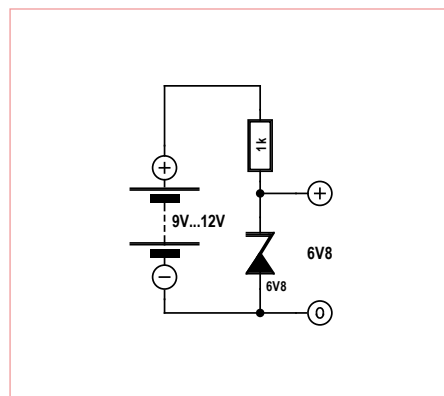


Figure 1. Voltage stabilisation with a Zener diode.

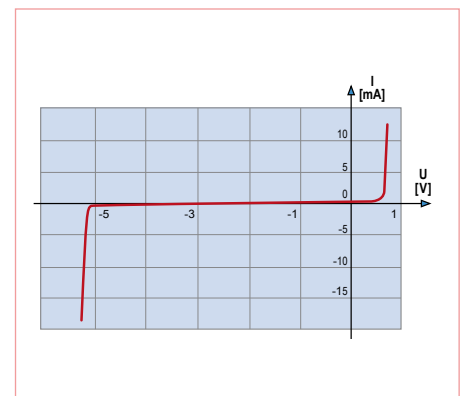
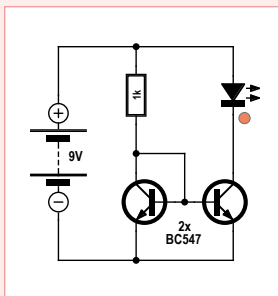


Figure 2. Characteristic curve of a Zener diode.

Current mirror

A current mirror, as illustrated by this circuit, is a distant cousin of a constant-current source. The (constant) current through the $1\text{ k}\Omega$ resistor is mirrored by the two transistors, and the collector current of the right-hand transistor is nearly the same as the that of the left-hand transistor. The base and collector of the left-hand transistor are connected together, which causes the base-emitter voltage to automatically assume a value that results in the specified collector current. In theory, if the second transistor has the same characteristics it should have the same collector current at the same base-emitter voltage. In practice, the current is usually slightly different because it's difficult to obtain identical transistor characteristics. This circuit is primarily used in ICs, where a large number of transistors on the same chip have the same characteristics.



It's also important that both transistors have the same temperature, since the transfer characteristics are temperature dependent. A current mirror of this sort can therefore be used as a temperature sensor. Try touching one of the transistors with your finger. The resulting heating changes the output current, which can be seen from the change in the brightness of the LED. Depending on which of the two transistors you touch, you can make the LED a bit brighter or a bit darker. The temperature dependence of the current mirror is actually a drawback of this circuit. This sort of thing is often seen in electronics, where something that is an undesirable 'degrading' effect in one situation is a desirable 'useful' effect in another situation.

package (such as the BC140 in a TO5 package) with the package opened up, you can see this light if you work in absolute darkness. Let's hear it for silicon LEDs!

Efficiency

Although voltage stabilisation with a Zener diode is easy, it has some drawbacks. One of the major drawbacks is power dissipation. This results from the fact that the series resistor must be dimensioned for the lowest input voltage and the highest output current. For example, if the circuit shown in Figure 4 has to supply a maximum current of 2 mA , the maximum output power is just 18 mW . The voltage over the series resistor is 3 V at the lowest input voltage of 12 V . This means that 1 mA flows through the Zener diode and 2 mA flows through the load. A current of less than 1 mA through the Zener diode is undesirable because it places the operating point on the knee of the characteristic curve, resulting in higher

internal resistance and poorer voltage stabilisation. However, even at this current level one-third of the input current is 'wasted' in the Zener diode. With even higher load requirements, the recommended minimum Zener current is 5 mA .

Things are even worse when the input voltage rises to 24 V . In this case the voltage drop over the series resistor is 15 V and the current is 15 mA . The resulting total input power is 360 mW . Compared with the useful power of 18 mW , this yields an efficiency of just 5% , which is terrible and is hardly tolerable in times of energy crisis. Fortunately, there is a solution to this problem.

Series regulators

Efficiency can be improved significantly if the Zener diode is followed by a transistor operating in common-collector mode, with the collector of the transistor connected directly to the positive terminal of the supply voltage (Figure 5). This type of circuit is

also called an emitter follower because the voltage on the emitter always follows the voltage on the base, with an offset of 0.6 V . In the present case the emitter voltage is 5.6 V ($6.2\text{ V} - 0.6\text{ V}$).

Here the Zener circuit only has to supply the base current for the transistor. As a result, the input current is only slightly higher than the output current of the circuit over a wide range of operating conditions. Most of the power dissipation occurs in the series-pass transistor, and it depends only on the output current and the difference between the input voltage and the output voltage.

Only a small change is necessary to convert this circuit into an adjustable voltage regulator. As shown in Figure 6, a potentiometer acts as a voltage divider for the stabilised auxiliary voltage. The output voltage is always approximately 0.6 V lower than the voltage on the wiper of the potentiometer.

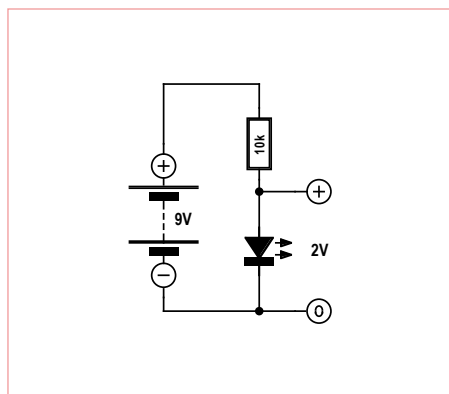


Figure 3. Voltage stabilisation with an LED.

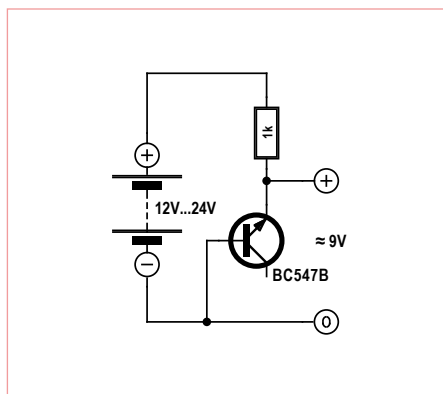


Figure 4. Using an NPN transistor as a Zener diode.

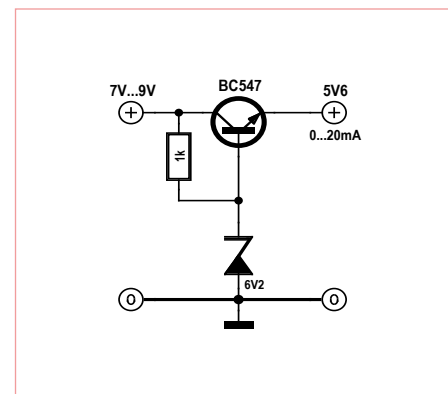


Figure 5. Using a transistor as a series regulator.

Voltage monitor

Many circuits require an operating voltage of 5 V and have a maximum tolerance range of $\pm 10\%$. In such cases it's a good idea to monitor the actual voltage. Here we want to use a microcontroller to monitor the voltage and generate suitable indications. A green LED should light up when the voltage is within the tolerance range (4.75 to 5.25 V). A red LED should light up if the voltage is too low, and a yellow LED should light up if it is too high. The microcontroller operates from the voltage that it monitors. It compares this voltage with an internal reference voltage of 1.1 V.

The source code file for this project, *Tiny13_V-V_monitor.bas*, can be downloaded free of charge from www.elektor.com/120005.

```
'Voltage Monitor
$regfile = "attiny13.dat"
$crystal = 1200000
$hwstack = 8
$swstack = 4
$framesize = 4

Dim U As Word

Config Adc = Single , Prescaler = Auto , Reference = Internal
Start Adc
Ddrb = &H07                'B0/1/2 outputs

Do
  U = Getadc(3)             '0..6.1V

  If U < 797 Then           '4.75 V
    Portb = &H04            'red
  Else
    If U > 880 Then         '5.25 V
      Portb = &H01          'yellow
    Else
      Portb = &H02          'green
    End If
  End If
  Waitms 1000
Loop

End
```

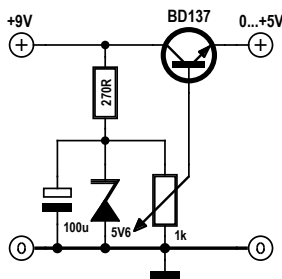
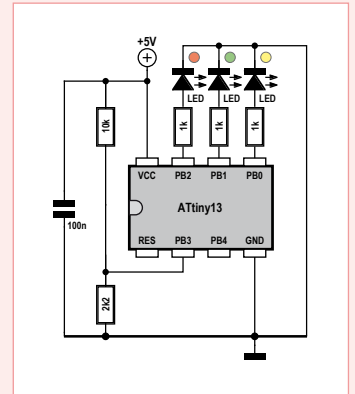


Figure 6. An adjustable voltage regulator.

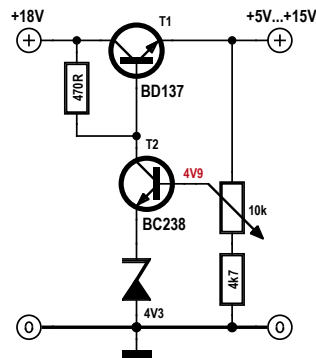


Figure 7. An improved adjustable voltage regulator.

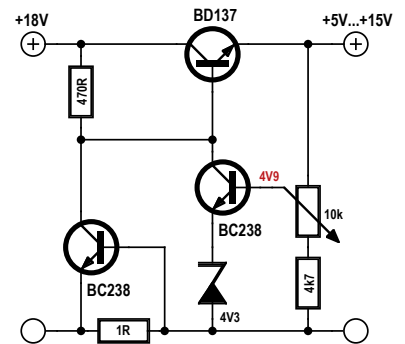


Figure 8. Adding current limiting.

To ensure adequate stability with variable output current, the current through the potentiometer must be greater than the maximum base current.

Even better stabilisation can be achieved by using an active output voltage follower, as shown in **Figure 7**. Here an adjustable portion of the output voltage is compared with the voltage on the Zener diode. The difference forms the error input to the control circuit, which drives the base voltage of series-pass transistor T1 via transistor T2. With this circuit it is possible to obtain an output voltage that is significantly higher than the Zener voltage, and which is close to the input voltage. This circuit can be used to build an adjustable power supply for cur-

rents up to 1 A. The actual load capacity depends on the cooling of the BD137 power transistor.

All that's missing here for a full-fledged adjustable power supply is current limiting. For this purpose, we insert a small resistance in the negative lead (**Figure 8**). The voltage drop over this resistor is proportional to the output current. The extra transistor starts conducting when this voltage drop rises above 0.6 V or so. This reduces the base voltage of the series-pass transistor. With a 1 Ω current sense resistor, the maximum possible current in the event of a short circuit is 0.6 A. However, the power dissipation of the series-pass transistor is very high in this situation. It won't be able to handle this without a large heat sink.

Integrated voltage regulators

It's good that low-cost integrated voltage regulators are available for all common output voltages. A 7805 can deliver up to 1 A at 5 V, although a heat sink is necessary at such high current levels. In many situations the current is much lower, and in such cases the 78L05, with a maximum current rating of 100 mA, is sufficient. However, you should note that the 78L05 has a different pinout than its larger cousin. These voltage regulators require two capacitors — one at the input and the other at the output — to prevent oscillation at frequencies of several hundred kilohertz (**Figure 9**).

These voltage regulator ICs contain everything already described in this instalment of our basics course using discrete semicon-

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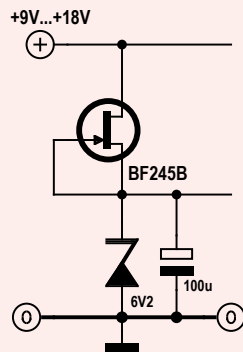
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The following voltage stabilisation circuit is intended to provide approximately 6.2 V, and it uses a BF245B JFET instead of a series resistor. The JFET is used as a simple constant current source in order to improve stabilisation with variable input voltage. The circuit is intended to be used with an input voltage range of 9 to 18 V.



1) What is the maximum current that can be drawn from the output?

- A) Just under 10 mA
- B) Up to 100 mA
- C) Less than 1 mA

2) How does the efficiency with high input voltages compare to the efficiency of a Zener diode circuit with a series resistor?

- D) The efficiency is better with the JFET.
- E) The efficiency is worse with the JFET.
- F) The efficiency is the same.

3. What is the purpose of the electrolytic capacitor in the circuit?

- G) It improves the efficiency.
- H) It reduces the internal impedance at high frequencies.
- I) It is intended to continue supplying power for a few minutes in the event of a power failure.

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The correct answer code for the March 2012 quiz is 'BDI'.

Here are the explanations:

1. The voltage over the collector resistor is 2.2 V (5 V – 2.8 V). The collector current is therefore 1 mA (ignoring I_B). The base-emitter voltage is around 0.6 V, so the voltage over the base resistor is 2.2 V (2.8 V – 0.6 V). This means that the base current is 4.68 μ A (2.2 V / 470 k Ω). The current gain is therefore 213.7 (gain = I_C/I_B = 1 mA / 0.00468 mA). Answer B is correct.
2. With no base current (answer E) you would measure a collector-emitter voltage of 5 V. With a very low base resistance (answer F) the voltage would be around 0.6 V. In any case, you would never measure 0 V in this circuit with an intact transistor. The transistor therefore has an internal short between the emitter and the collector. This can happen if the transistor is overloaded (second-breakdown failure).
3. The (wrong) answers G and H would be good candidates if no current at all flowed through the collector resistor. However, if the collector and emitter leads of a transistor are reversed, it still operates as a transistor but with much lower current gain (reduced by a factor of 3 to 20). With a measured U_{CE} of 4.9 V, the calculated current gain is approximately 5. This means that the transistor has been fitted the wrong way round.

ductor devices. If you examine the internal circuit shown in **Figure 10**, you will see a lot of familiar things, such as the Zener diode with its series resistor. The actual control circuit is somewhat more complicated and includes a differential amplifier as well as a current mirror (see inset). The series pass transistor is implemented as a Darlington pair consisting of Q11 and Q12, with most of the power dissipation occurring in Q12. Current limiting is handled by transistor Q10, which chokes off the base current to the Darlington pair Q11/Q12 if and when necessary. As might be expected from the 3 Ω value of the current sense resistor, the cutoff current is 200 mA. However, the IC is already very hot at this point, since the voltage on the base of Q10 is less than 0.6 V. The IC is protected against overcurrent and overtemperature. The overtemperature protection circuitry is built around Q7, Q8 and Q9.

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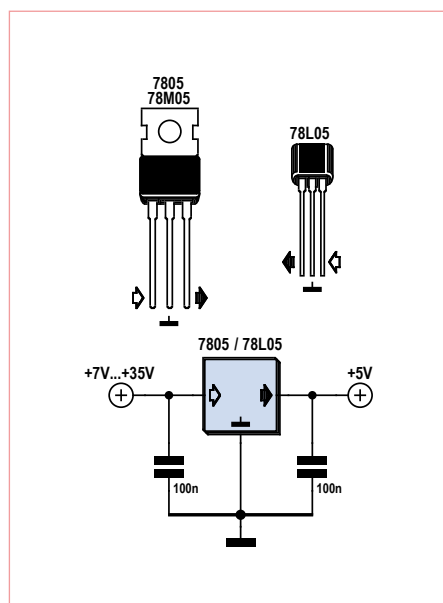


Figure 9. 780x voltage regulator circuit with bypass capacitors.

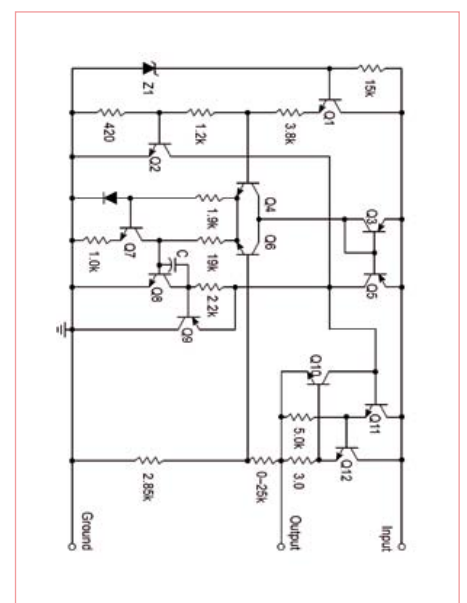


Figure 10. Internal structure of a 78Lxx (source: Motorola).

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AM and FM, plus an active ferrite antenna

As this series shows, the popular AVR microcontroller can be used for digital signal processing tasks. In this instalment we will look at a few experiments involving amplitude and frequency modulation, including a small DCF time code test transmitter. We will also extend the hardware by adding an active ferrite antenna which will allow longwave and mediumwave signals to be received.

tered on the point where the counter hits zero and thus has constant phase. If we filter the squarewave PWM output using a resonant circuit to generate a sinewave, we can calculate the amplitude \hat{A} of the result using the formula $\hat{A} = A \times (4 / \pi) \sin(D \times \pi)$, where D is the mark-space ratio of the squarewave and A its amplitude.

This takes us neatly into our first experiment, which uses the signal generator and the universal receiver board (or the ‘simple front-end’ described in [2]). The transmitter routine is simple in structure, as illustrated in the **Listing**. The software for the signal generator, in file `EXP-SQTX-125kHz-PWMC-V01.c`, is as usual available for download from the project web pages [3]. At the receiver end we use the program `EXP-SimpleFrontend-125kHz-Phase-Ampl-V01.c`.

If we connect the two outputs of the receiver to an oscilloscope the result will be as shown in **Figure 1**. The value in req-

ister OCR1A is being switched between 8 and 40, which corresponds to switching the mark-space ratio of the output between 0.1 and 0.5. The amplitude ratio in this case is $\sin(0.1 \times \pi) / \sin(0.5 \times \pi) = 0.309016... = -10.200 \text{ dB}$. Since the 'amplitude' output of the receiver has a scale of 1 V per 20 dB, the voltage difference between the two levels is about 0.5 V (see the yellow trace). The other output of the receiver gives the phase of the received signal. As can be seen (blue trace) this is not affected by the modulation. There is, however, a gentle drift which is a result of the frequency difference between the transmitter and the receiver.

With what we have developed so far we can build ourselves a DCF time code test transmitter. The DCF77 time code transmitter is located in Mainflingen, Germany, and has a range of about 1,200 miles. The carrier frequency of 77.5 kHz unfortunately does not

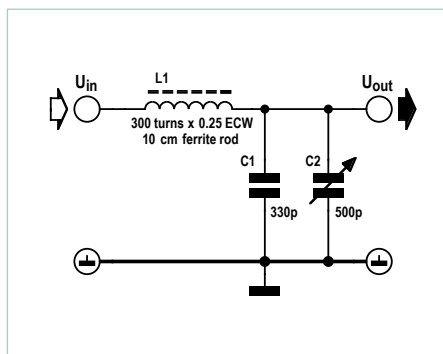


Figure 2. DCF77 transmitter tuned circuit.

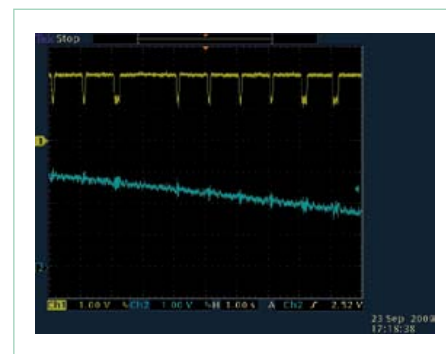
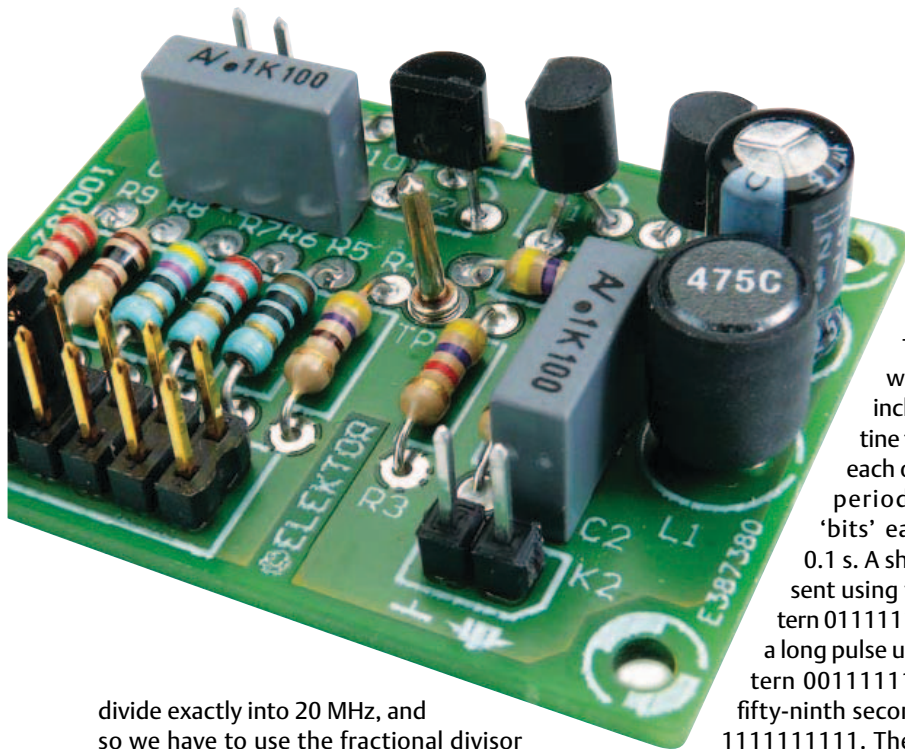


Figure 3. DCF77 reception. The short and long pulses can be seen in the yellow amplitude trace.



divide exactly into 20 MHz, and so we have to use the fractional divisor technique along with a 24-bit DDS accumulator and a timer interrupt as described in the first instalment of this series [1]. In this new code, however, we will generate 'phase correct' PWM, as we do not want any phase modulation on the output.

We feed the PWM output of the signal generator into a resonant circuit (**Figure 2**) consisting of a ferrite antenna and a suitable capacitor. An additional variable capacitor allows us to trim the circuit for maximum output amplitude.

The code running in the ATtiny microcontroller in the signal generator is `DCF_TX_V01.C`, which produces messages compatible with the DCF77 time code. Each message is composed of pulses that start at the beginning of each second, the time information being conveyed by whether the pulse is a short or a long reduction in signal amplitude. No pulse is sent in the fifty-ninth

second of each minute. The software includes a routine that divides each one-second period into ten 'bits' each lasting 0.1 s. A short pulse is sent using the bit pattern 011111111, while a long pulse uses the pattern 001111111. In the fifty-ninth second we send 111111111. The complete message is built by concatenating these three templates.

The program initialises the time to 11:41 on 15 August 2008. If the resonant circuit is correctly adjusted it is possible to set the time on DCF-controlled clocks within a radius of a couple of metres. Most such devices correct their time only fairly infrequently, but can usually be prodded into adjusting themselves by briefly removing the battery.

DCF77, part two

We would also like to be able to receive the real DCF time code from Germany. To do this we need the active ferrite antenna that is described later in this article, and which is available as a kit from *Elektor*. The antenna is connected to the ANT2 connection on the receiver board. On the receiver board itself we connect pin 1 of K4 to pin 2 of K5

Listing: Phase correct PWM

```
void bitSend(uint8_t theBit){
  if (theBit)
  {
    OCR1A = 40;
  }
  else
  {
    OCR1A = 8;
  } // 10dB
}
```

so that the input signal is taken to the ADC0 input of the ATmega. The software used is `EXP-Simple-DCF77-RX-V01.C`.

We sample the input signal at 10 kSa/s. Since 77.5 kHz is exactly $8 \times 10 \text{ kHz} - 10 \text{ kHz} / 4$, we can do the demodulation using the bandpass sub-Nyquist sampling technique described in the previous instalment of this series. The oscilloscope traces in **Figure 3** show the results. The upper (yellow) trace shows the amplitude, with the short periods when the amplitude is reduced clearly visible. It is also possible to see that both long and short reductions in amplitude are present. Extracting the time information is now just a short step away.

We can also make use of the phase component of the DCF77 signal. In one of our later experiments we will clock the receiver using a voltage-controlled 20 MHz crystal oscillator (VCXO) rather than a fixed-frequency oscillator. If we adjust the frequency of the oscillator so that the phase no longer drifts, the 20 MHz signal will be

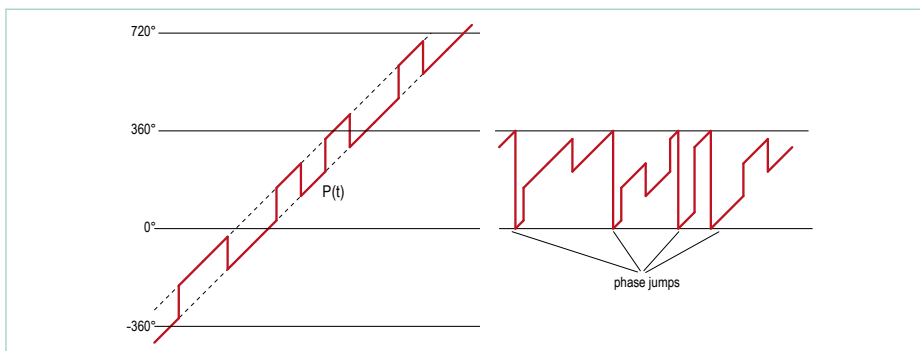


Figure 4. The same phase behaviour shown in two different ways.

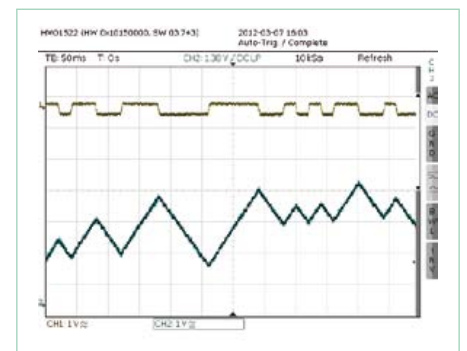


Figure 5. Frequency shift keying (FSK).

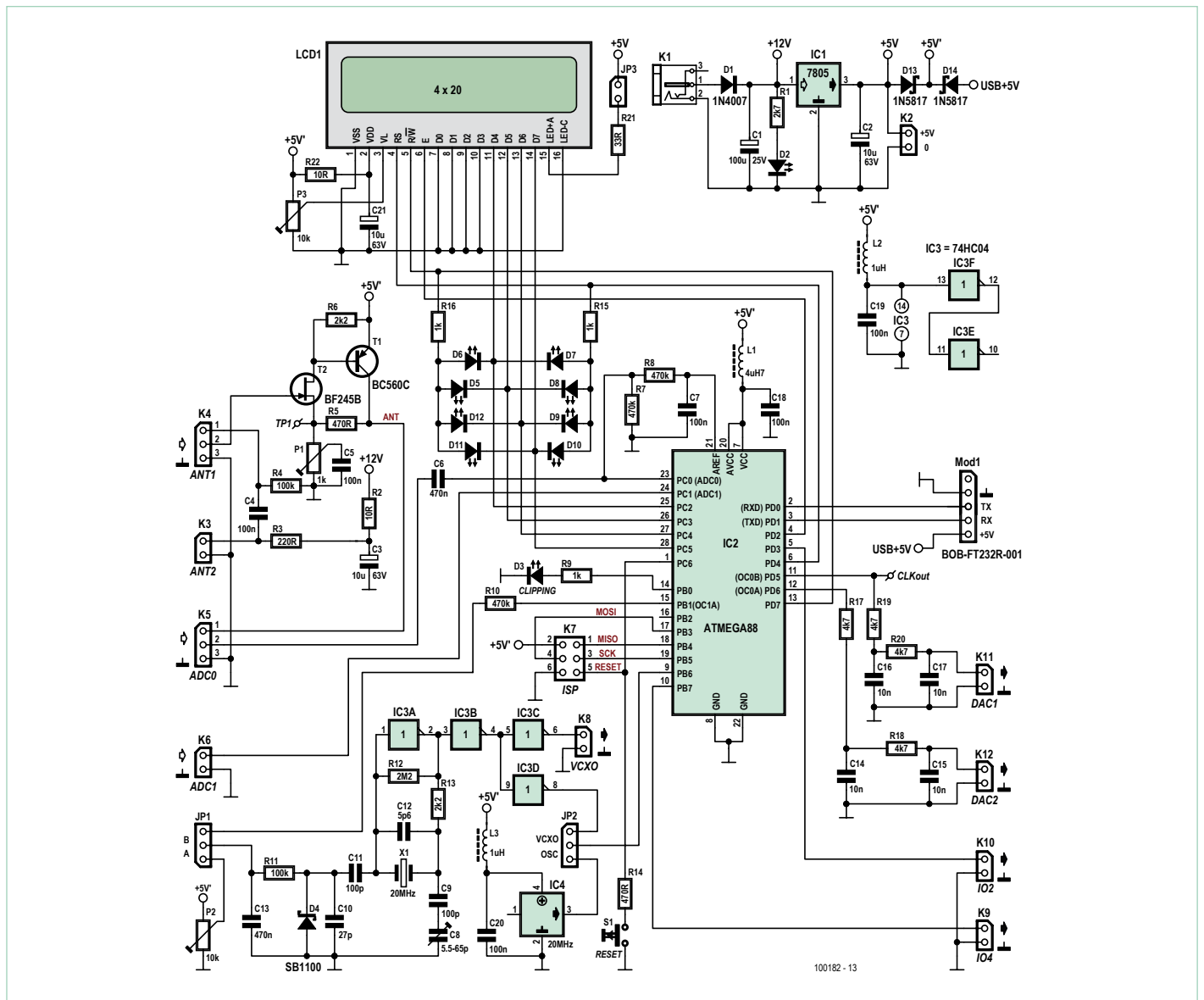


Figure 6. Circuit diagram of the AVR-SDR universal receiver board.

locked to the very precise carrier frequency of the DCF77 transmitter. In Figure 3 it is possible to see the phase changing slowly: by using a phase-locked loop it is possible to automate the adjustment, as we shall see later in this course. It is also possible to lock the receiver to other sources, such as BBC Droitwich transmissions on 198 kHz or France Inter on 162 kHz, both of which also provide very precise frequency references.

Understanding the phase changes

Figure 1 shows the by now familiar saw-tooth pattern in the phase angle that results from a frequency offset between transmitter and receiver. The phase changes smoothly, wrapping round between

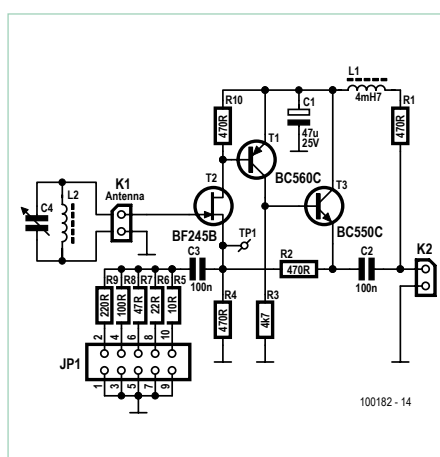


Figure 7. Circuit diagram of the active ferrite antenna.

360 degrees = 5 V and 0 degrees = 0 V. The wrap-around appears sudden on the oscilloscope trace, but the underlying physical behaviour is continuous.

We can often get a clearer picture if, rather than restricting the angle to lie between 0 degrees and 360 degrees, we allow it to go below 0 or beyond 360. In Figure 4 on the left we can see a representation in this form of a phase-modulated signal with a frequency offset superimposed. The curve is rather easier to interpret than when the phase angle is restricted.

A couple of analogies may help to explain what is happening. First imagine walking in a circle around the north pole: at a certain point, which has no particular significance on the ground, your longitude

will jump between 180 degrees west and 180 degrees east. Now imagine not walking in a circle, but climbing a spiral staircase. After one complete revolution you are not in exactly the same place: you are one floor higher. If, along with the phase angle, we keep track of which 'floor' we are on, we can represent phase differences of more than 360 degrees. This is a technique used in constructing PLLs that have a wide capture range.

Figure 5 shows a nice application of this technique. We use our signal generator as an FSK (frequency shift keying) transmitter, using the software in `EXP-SQTX-FM-RTTY-V01.c`. The output of the signal generator on K4 is taken via a resonant circuit acting as a filter (see the first part of this series [1]) to input ADC0 on the receiver. The code running in the receiver is `EXP-SimpleFrontend-125kHz-extPhaseFreq-V01.c`, which has a phase output scaled so that it can represent a wider range of phases. The scaling is such that 5 V represents 8×360 degrees. The 125 kHz carrier generated by the transmitter is shifted by ± 50 Hz to represent the bits 1 and 0, and the data rate is 50 bits per second. A shift of ± 50 Hz means that in one bit time, $1/50$ s, the transmitted signal will gain or lose one period relative to the reference signal. Each bit thus corresponds to a phase shift of 360 degrees with a direction that depends on the value of the bit being sent. In turn, a phase change of 360 degrees gives a change in the output voltage of $5 \text{ V} / 8 = 0.625 \text{ V}$, and this occurs over a period of 20 ms. The blue trace in Figure 5 shows this effect clearly.

Demodulating the FSK signal is easy: the instantaneous rate of change of phase corresponds to the current frequency shift and hence to the transmitted bit. The rate of change of phase can be calculated by taking the difference between consecutive phase values: the result is shown in the yellow trace. When the phase angle is increasing the yellow trace is 'high'; when it is decreasing, the trace is 'low': from this it is easy to read off the bits being sent. A software UART can be added to make a complete software defined FSK receiver. In the next instalment of this series we will see how a

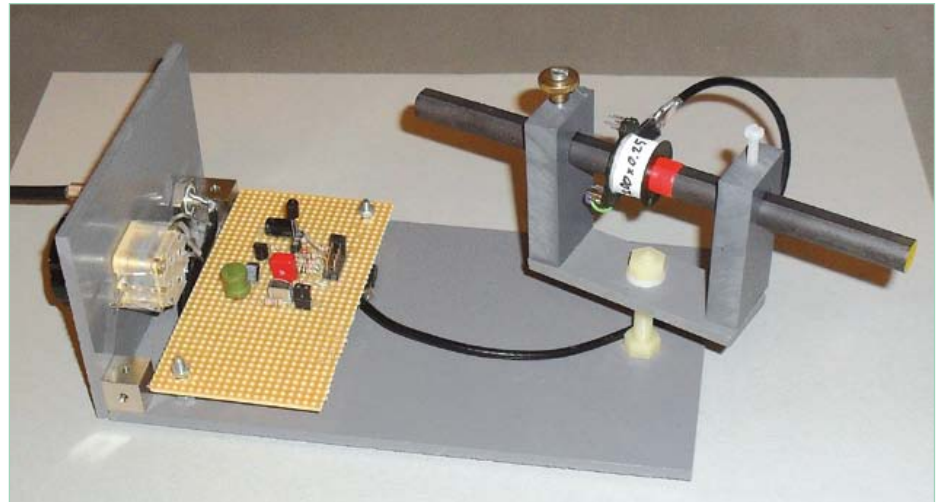


Figure 8. The author's prototype of the active ferrite antenna.

couple of extra filters can be added to make the receiver more robust.

The universal receiver board

Now that we have carried out a few experiments with the simple receiver circuit, it is time to move on to a more advanced receiver board. The universal receiver board was described, including a printed circuit board layout, in the previous instalment of this series. **Figure 6** shows the circuit diagram again to help explain some of the interesting possibilities that it opens up. A four-line LCD panel is provided as a display. Header Mod1 allows a BOB-FT232R USB-to-TTL converter to be added: this lets you communicate between the board and a PC, for example to log received data.

A discrete 20 MHz oscillator is provided as a clock source. The frequency of this oscillator can be adjusted over a narrow range using a control voltage. This voltage is derived either from potentiometer P2 or from the AVR microcontroller itself via PWM output OC1A/PB1 and a lowpass filter comprising R10 and C13. This latter option allows the VCXO to form part of a phase-locked control loop, for example to derive a precision frequency reference from the DCF77 signal. A divided-down version of the clock frequency can be output on pin OC0B. Alternatively, an integrated quartz crystal oscillator module (IC4) can be selected to provide the master clock using jumper JP2.

Ports C and D are used to drive eight LEDs arranged in a circle that can be used as a phase display. These provide a simple means of determining when the PLL is in lock, and give a clear indication when a small frequency offset is present.

Analogue signals are presented to the microcontroller on the ADC0 input to its analogue-to-digital converter. R7 and R8 provide a DC offset voltage on this input equal to half the converter's reference voltage AREF, while C6 provides AC coupling for the input. T1 and T2 form a pre-amplifier to whose input (K4 pins 2 and 3) a resonant receiver circuit consisting of a ferrite antenna and a tuning capacitor can be directly connected. The output of the preamplifier can be fed to the ADC input by connecting together pins 1 and 2 of K5. Another possibility is to connect a ferrite antenna with phantom power to the pre-amplifier input: in this case pins 1 and 2 of K4 should be connected together and the ferrite antenna connected to K3.

For some of the experiments we have seen so far (and for some in the future) we have generated two outputs from the receiver and visualised them using an oscilloscope. These outputs are generated using PWM based on Timer 0 and are available on pins OC0A and OC0B. Each of these is equipped with a two-stage RC filter. The resulting voltages are available on K11 and K12.

Active ferrite antenna

To complete the picture we equip our receiver with an active ferrite antenna for the longwave and mediumwave bands. **Figure 7** shows the circuit diagram. Thanks to JFET T2 the input has a very high impedance, and so the tuned circuit forming the antenna has a high Q-factor and selectivity. T1 provides a useful amount of gain and emitter follower T3 gives a low-impedance output. Resistor R2 gives negative feedback for DC and AC, the latter being configurable

COMPONENT LIST Active ferrite antenna

Resistors

(all 5%, 0.25W)
R1,R2,R4,R10 = 470Ω
R3 = 4.7kΩ
R5 = 10Ω
R6 = 22Ω
R7 = 47Ω
R8 = 100Ω
R9 = 220Ω

Capacitors

C1 = 47µF 25V, 20%, radial, 2.5mm, I_{AC} 95mA
C2,C3 = 100nF 63V, 5%, MKT, 5mm or 75mm
C4 = 2x265pF + 2x20pF dual gang quad section tuning capacitor (e.g. [4])

Inductors

L1 = 4.7mH, 81mA, 132Ω, radial, 3mm
L2 = ferrite rod, L = 90mm, D = 10mm (e.g. [4])
3 pcs coil former, 10mm, 5-pin
24.5m (82 ft.) enamelled copper wire, 0.22mm diameter (#31 AWG)

Semiconductors

T1 = BC560C
T2 = BF245B (JFET)
T3 = BC550C

Miscellaneous

K1,K2 = 2-pin pinheader, lead pitch 0.1 in. (2.54mm)
JP1 = 10-pin pinheader, lead pitch 0.1 in. (2.54mm)
TP1 = PCB solder pin, 1.3mm diam.
PCB # 100182-1 [3]

Alternatively: kit, comprising PCB and all parts: # 100182-71 [3]
Alternatively: Combined kit; 3 kits plus BOB FT232 USB/TTL-converter: # 100182-72 [3]

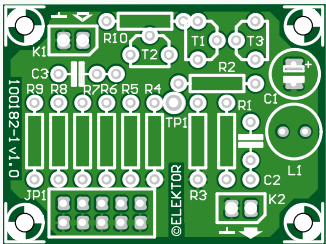


Figure 9. The printed circuit board for the active ferrite antenna is available from Elektor as part of a kit, along with all the components.

the universal receiver board a complete kit for the active ferrite antenna is available from Elektor including all components and a printed circuit board (Figure 9). The kit includes a ferrite rod, three coil formers and 24.5 m of enamelled copper wire.

RMS voltmeter with random sampling

At various points in this course it is useful to be able to measure the RMS value of an alternating voltage. For example, one application is in adjusting a ferrite antenna to a given frequency with the help of the signal generator. As it happens, we can turn our receiver board into an RMS voltmeter! In principle, to calculate the RMS value S_{RMS} of a periodic signal $s(t)$ we need to take a sufficiently large number N of samples s_k over a period and then compute the ‘quadratic mean’:

$$S_{RMS} = \sqrt{ (1/N \sum s_k^2) }$$

Now, we would like to work with signals whose frequencies are as high as 1 MHz, and the ATmega88 cannot sample its input sufficiently fast (the limit is about 10 kSa/s at 10-bit precision). Instead of taking many samples over a single period, however, we can take readings at random points in time over many periods (see Figure 10), in a technique called ‘random sampling’. The disadvantage of this approach is that a relatively large number of samples is required to get a sufficiently accurate result. On the other hand, it has the advantage of working equally well with non-periodic noise-like signals. The ATmega88 random sampling RMS voltmeter code is contained in the file EXP-RMSmeter-V01.c. The program automatically switches the A/D converter’s reference voltage between 5 V and 1.1 V as needed to obtain the best possible accuracy. The quadratic mean is calculated over a total of 2048 samples, and simultaneously displayed on the receiver board’s LCD panel and output on its serial interface. The display is then updated after every 256 new samples. As we describe in the ‘Aperture time’ text box, this RMS voltmeter is an entirely practical piece of equipment.

Table: Ferrite antenna and tuning capacitor details		
AK Modul-Bus dual-gang tuning capacitor 2 × 265 pF, C _{min} = 50.00 pF, C _{max} = 500.00 pF		
AK Modul-Bus ferrite antenna, 90 mm long, AL = 100.00 nH / n ² (experimentally determined value, depends on the coil geometry and other factors)		
Wind 50, 150 and 200 turns on each of three coil formers to allow total turns counts of 50, 200 and 400.		
Turns	Inductance	Frequency range
n = 50	L = 0.250 mH	450.2 kHz to 1423.5 kHz
n = 200	L = 4.000 mH	112.5 kHz to 355.9 kHz
n = 400	L = 16.000 mH	56.3 kHz to 177.9 kHz

using JP1. The antenna receives phantom power at approximately 12 V. Part-to-part variation in T2 can affect the function of the circuit. It is therefore necessary to select T2 so that the voltage at its source is around 2 V. It is also necessary to

ensure that the input connections are kept away from the output connections as otherwise feedback can cause the circuit to oscillate, and it is best to use screened cables. Figure 8 shows the author’s prototype. As in the case of the signal generator and

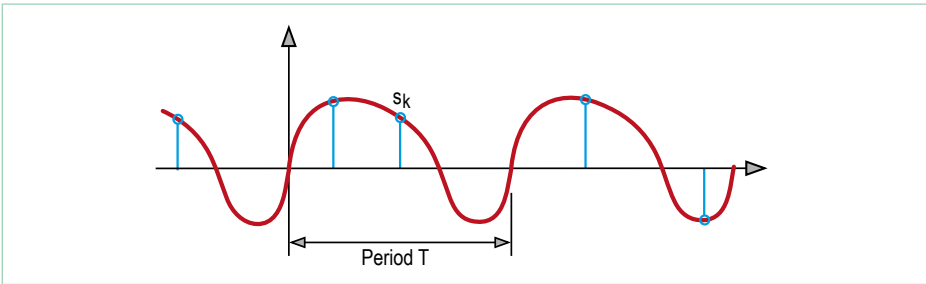


Figure 10. Random sampling.

Aperture time

The ATmega88 requires a total of 13 ADC clock periods to carry out a conversion, and the maximum ADC clock frequency is 200 kHz. In our case we generate the ADC clock by dividing the 20 MHz CPU clock by 128, which gives a frequency of 156.25 kHz and a conversion rate of about 12 000 conversions per second. According to the sampling theorem this lets us digitise any input signals that do not contain frequency components above 6 kHz. Despite this, the random sampling technique lets us measure the RMS value of signals with considerably higher frequency components. The limiting factor in this is the quality of the sample-and-hold circuit in the microcontroller immediately before the converter itself. In particular, the time period over which the input is sampled (called the 'aperture time') must be as short as possible. Unfortunately the ATmega88 datasheet does not give precise information on this point, and so we need to do some experiments to find out the maximum frequency for which we can get a respectable level of accuracy in our measurement of RMS value.

No sooner said than done: the author set up a test with a 100 mV_{RMS} sinewave signal fed simultaneously into the AVR RMS meter and a Tektronix digital oscilloscope. The table gives the amplitude readings shown for frequencies of up to 2 MHz. Up to 200 kHz our device gives good accuracy; at 500 kHz the error is around 10 %; and at 1 MHz the error is around 30 %.

It seems from these results that it is possible to sample frequencies of up to a few hundred kilohertz reasonably accurately. If we are prepared to allow for the 30 % (about 3 dB) attenuation, then we can work with frequencies of up to 1 MHz. The conclusions are twofold: first, our RMS voltmeter is not bad at all; and second, the aperture time of the AVR microcontroller is rather short, which will come in handy later when we look at digitising signals in the longwave and mediumwave bands using sub-Nyquist sampling.

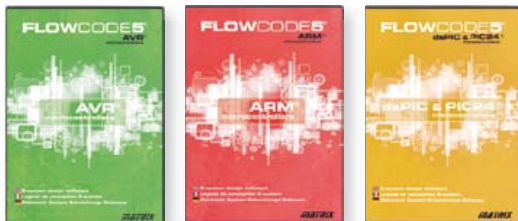
Frequency	AVR display (mV)	Oscilloscope (mV)
1 kHz	99.0	100.0
2 kHz	100.0	100.0
5 kHz	101.9	101.5
10 kHz	102.0	102.0
20 kHz	102	102.5
50 kHz	102	102.3
100 kHz	101	102.2
200 kHz	98.0	101.7
500 kHz	90.0	101.0
1 MHz	68.0	100.9
2 MHz	42.0	99.0

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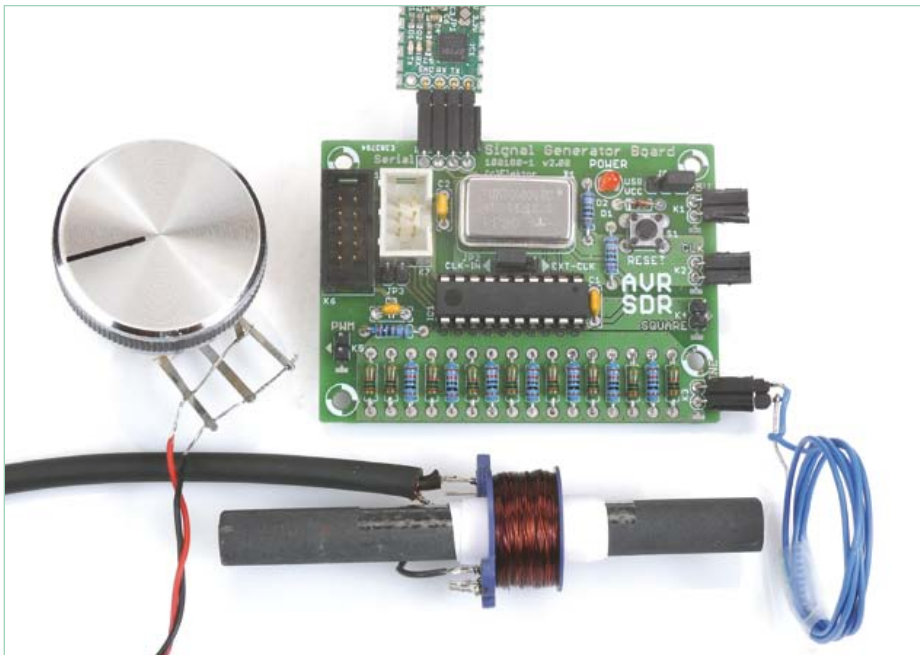


Figure 11. Set-up for adjusting the ferrite antenna tuned circuit.

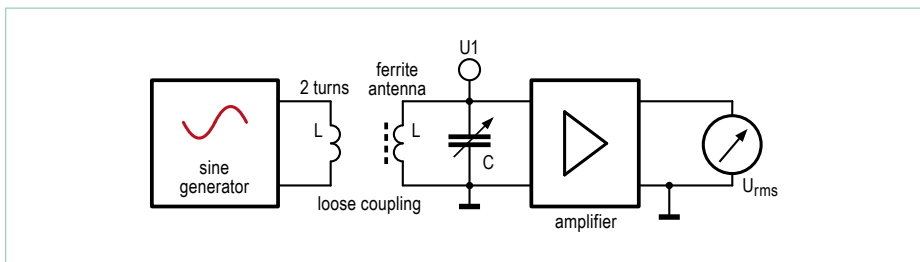


Figure 12. Schematic arrangement of components for adjusting the ferrite antenna tuned circuit.

The ferrite antenna and its adjustment

The carrier frequencies used by transmitters that we will want to receive lie between 50 kHz and 700 kHz. In this range a ferrite antenna is the best choice. We use a ferrite rod 90 mm long and with a diameter of 10 mm (available, for example, from AK Modul-Bus [4], and included in the kit). An RM10 coil former can be used to wind suit-

able coils. To cover the above frequency range using a dual-gang 2×265 pF tuning capacitor we can use three separate coils, with 200, 150 and 50 windings (see **Table**). When hunting for a signal it is necessary both to tune the antenna and adjust its orientation. It makes life easier if the tuning part has been done accurately in advance, and we now have at our disposal all the equipment we need to do this. The signal

generator is set up to produce sinewaves (EXP-SinusGenerator-DDS-ASM-C-V01.c), which we feed into a small 30 mm diameter coil wound with just a few turns of wire (**Figure 11**), making a 'magnetic' test transmitter.

It is best to set up the resonant circuit in the receiver in exactly the configuration in which it will subsequently be used. For example, connecting an oscilloscope to the circuit will shift its centre frequency significantly.

First connect the active antenna to the receiver board and run the RMS voltmeter 'receiver' software EXP-RMSmeter-V01.c. **Figure 12** shows the arrangement schematically. Now set the test transmitter to the desired frequency as described in the first part of this series [1]. Bring the transmitter coil up fairly close to the ferrite rod. Adjust the tuning capacitor until the receiver is at resonance with its output level at a maximum. To tune more precisely it may be necessary to move the transmitter coil further away from the ferrite antenna and adjust again. With the tuned circuit set to the correct frequency it is a lot easier to find the desired station.

In the next instalment we will continue with a look at filters and how to use a PLL to generate a high-precision frequency reference, and we will see how to receive marine weather information on 147.3 kHz.

(100182)

Internet Links

- [1] www.elektor.com/100180
- [2] www.elektor.com/100181
- [3] www.elektor.com/100182
- [4] www.ak-modul-bus.de (site in German only)

Elektor products and support

- Signal generator (kit including printed circuit board and all components): # 100180-71
- Universal receiver (kit including printed circuit board and all components): # 100181-71
- Active ferrite antenna (kit including printed circuit board and all components): # 100182-71
- Combined kit (all three of the above plus BOB-FT232R USB-to-TTL

converter): # 100182-72

- BOB-FT232R USB-to-TTL converter, ready built and tested: 110553-91
- USB AVR programmer, printed circuit board with SMDs fitted, plus all other components: 080083-71
- Free software download (hex files and source code)

All products and downloads are available via the web page accompanying this article: www.elektor.com/100182

Component Tips

By Raymond Vermeulen (Elektor Labs)

MOSFETs + extras

In this month's instalment and the next we will take a look at MOSFETs with unusual characteristics. Because quite a lot can be said about this subject, we will discuss only one component this time. When I first came across one of these components I realised that even as a professional electronics engineer one is continually learning new things. This encouraged me to share this knowledge with other electronics engineers via this regular monthly column. In this third article of the series we describe the 'current sense MOSFET'; next month we will look at the intelligent 'high-side switch'.

(120225)

BUK7105-40AIE

In many situations you would like to know how much current is flowing into a load. Sometimes you want to set the current in a branch exactly or you have a certain process in which the magnitude of the current is the feedback for a control loop. We normally measure the current in a circuit with the help of a shunt resistor, but the losses in such a resistor can often become unacceptable when the current is more than a few amps. Another disadvantage is that the dimensions of a shunt resistor for large currents are not inconsiderable. With the aid of the N-MOSFET described here, it is possible to make very accurate measurements without the need to add a shunt resistor in series with the load.

The BUK7105-40AIE [1] is a so-called TrenchPLUS FET, an automotive component with a gate that is protected against ESD and complies fully with the Q101 standards. How is one of these things put together? Design a small MOSFET cell, copy this a few thousand times on a piece of silicon and you will have a MOSFET with a low $R_{DS(on)}$ and which is capable of carrying a considerable amount of current. The manufacturer has taken advantage of this configuration by taking the drain of 1/500th of the cells out of the package on a separate pin (**Figures 1 and 2**). As a result, a current of 1/500th of the drain current flows out of this I_{sense} pin. There is an additional pin which is connected to the source of the FET. This is the so-called 'Kelvin connection', a term many of you will recognise in the context of a 4-wire measurement. And it is indeed related to that, with this pin you can measure the voltage at the source without any voltage drop across PCB traces getting in the way. **Figure 3** shows what a measuring setup with one of these FETs could look like. The schematic shows the virtual-earth method, which makes an accuracy of about 5% possible. The formula for the drain current in this circuit is:

$$V_{sense} = (-I_D \times R_{sense}) / n$$

Where n is I_D / I_{sense} , in this case, 500. Keep in mind though that you also need a negative power supply voltage for the opamps. The second opamp in **Figure 3** is only shown block diagrammatically, it is clear that this one has to invert to suit the A/D converter in the microcontroller. In the application note [2] another measuring method is described which is less accurate, but does not require a negative power supply voltage.

This is a component which is definitely of interest if you have to switch large currents and you want to have information about the amount of current that flows.

[1] www.nxp.com/documents/data_sheet/BUK7105-40AIE.pdf

[2] www.nxp.com/documents/application_note/AN10322.pdf

Parameter	Condition	Value (Typical)
$R_{DS(on)}$	$V_{GS} = 10 \text{ V}, I_D = 50 \text{ A}, T_j = 25^\circ \text{C}$	4.5 m Ω
$R_{D-I_{sense}(on)}$	$V_{GS} = 10 \text{ V}, I_D = 100 \text{ mA}, T_j = 25^\circ \text{C}$	1.08 Ω
I_D / I_{sense}	$T_j > -55^\circ \text{C}; T_j < -175^\circ \text{C}, V_{GS} > 10 \text{ V}$	500
$V_{GS(th)}$	$T_j = 25^\circ \text{C}, I_D = 1 \text{ mA}$	3 V

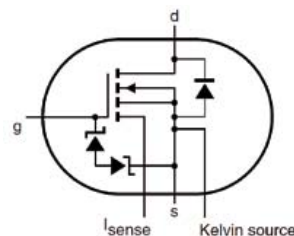


Figure 1. Schematic symbol.

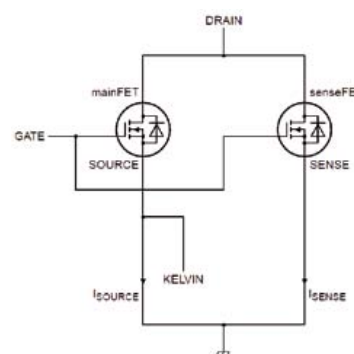


Figure 2. Equivalent circuit.

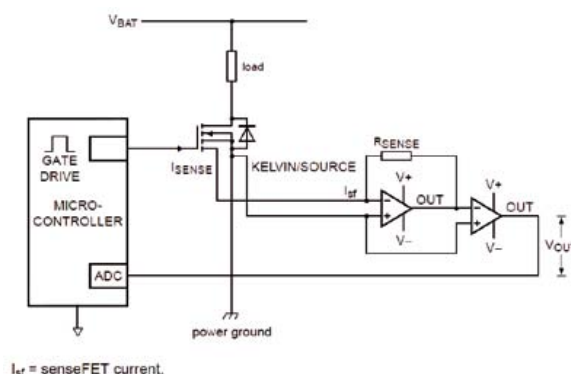
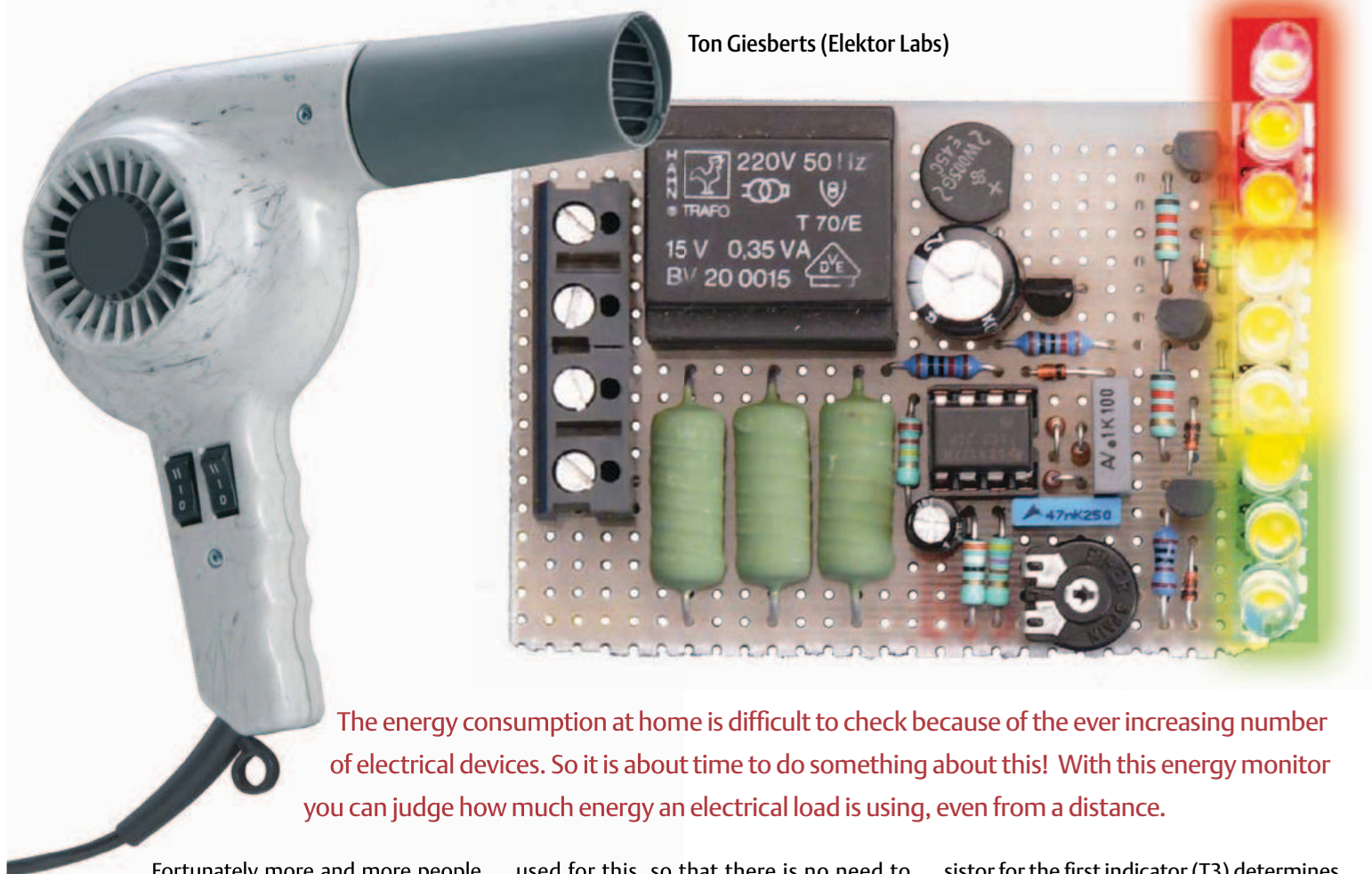


Figure 3. Application example for current measurement.

Energy Monitor

Luminous AC current indicator

Ton Giesberts (Elektor Labs)



The energy consumption at home is difficult to check because of the ever increasing number of electrical devices. So it is about time to do something about this! With this energy monitor you can judge how much energy an electrical load is using, even from a distance.

Fortunately more and more people are beginning to realise that we have to use energy sparingly. This is not only true for large companies, but at home it is also sensible to 'watch the small things'. So do not leave mains power adapters plugged in when not in use and actually turn electronic appliances off, instead of using the standby button. It is also good to get an idea as to how much energy each appliance uses. The intention is that this leads to more sensible use of these appliances at home.

For this purpose we designed an indicator which changes colour depending on the current consumption.

Operation and dimensioning

The operating principle of the circuit is very simple. By connecting a shunt in series with the load we can measure the current consumption. The parallel connection of R1 and R2 is suitable for measuring currents up to 14 A. Two standard 0.1 Ω /5 W resistors are

used for this, so that there is no need to search for difficult shunts. The dissipation at 10 A is not all that high at 5 W. This shunt can also be made from other resistor values, of course, and the exact resistance value is not important (because there is the opportunity to calibrate the circuit). A full-wave rectifier is built around IC1A. During the positive half cycle of the current through shunt R1/R2, D1 blocks and the input current passes via R3 and R4 to filter R5/C1. During the negative half cycle, IC1A amplifies the input signal such that the cathode of D1 has the same amplitude as the input. The voltage across C1 is a measure of the average value of the measured current. As thresholds for the indicator we chose 25 W, 75 W and 150 W. The corresponding voltages across C1 are about 4.9 mV, 15 mV and 29 mV. This means that quite a bit of gain is required before the 3 rows of LEDs can be driven with the aid of transistors. The base-emitter junction of the tran-

sistor for the first indicator (T3) determines how much the voltage across C1 has to be amplified so that it will start to conduct. If we assume a value of about 0.65 V, then the first switching threshold of 5 mV has to be amplified 130 times. This is what IC1B does. With P1 in the centre position the voltage across C1 is amplified a little more than 130 times. R12 limits the base current to T3. The transistors for the other 2 rows of LEDs, T2 and T1, have to be driven via voltage dividers. It is not difficult to calculate these: at 75 W the output of IC1B is at 1.9 V and at 150 W it is 3.8 V. In order to obtain a defined switching threshold it is necessary that the current through the divider is a little more than what is required for the base current. We selected a value of 0.5 mA. R11 and R9 then become 1k2. R10 and R8 then become 2k7 and 5k6 respectively.

To ensure that only one row at a time is lights up, T3 is switched off by T1 and T2,

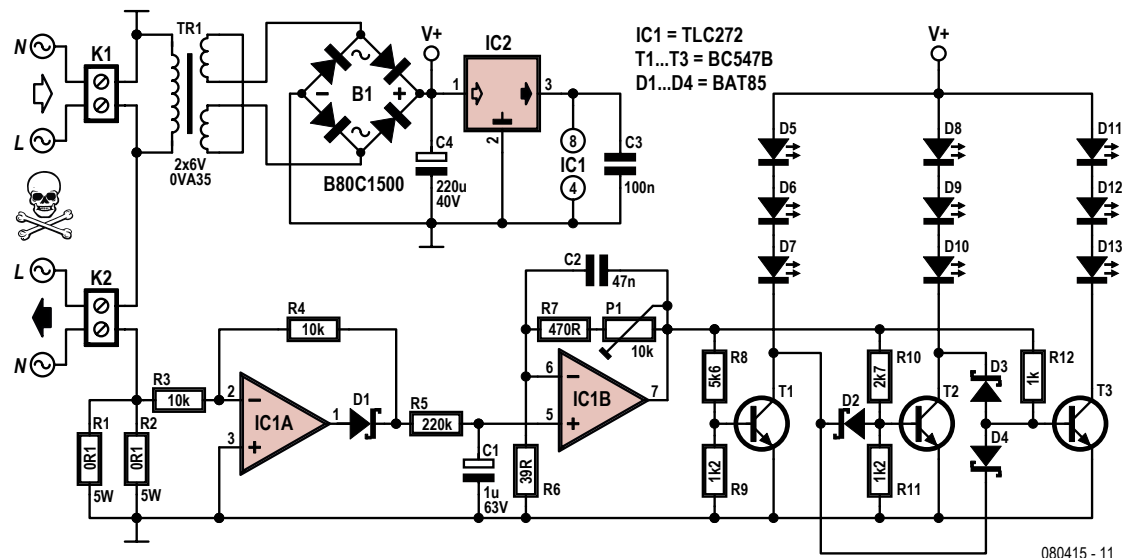


Figure 1. Three sets of white LEDs with colour filters show how much energy the appliance is using.

and T2 by T1. This is done with the aid of Schottky diodes type BAT85 (D2/D3/D4). The simplicity of this drive mechanism gives the circuit a nice touch. Just before D5 through D7 are fully illuminated, D8 through D13 will just start to turn on (at exactly the correct load, of course). This is because at the transition from T2 to T1 neither transistor is conduction sufficiently to ensure that T3 is fully turned off via D3 and D4. However, once the current increases a little more only D5 through D7 remain lit.

Three rows of white LEDs with colour filters are used for the colour indication. The reason that only white LEDs are used is to ensure that each of the branches are all identical in brightness, assuming that the filters do not influence the brightness too much. The advantage of this is that you can choose your own colours. Instead of the standard colours green/yellow/red, you could, for instance, use blue/lilac/purple. For the filters you could, for example, use discarded filters for PAR56 spot lights or something similar and cut these to the required size (such filters are also available separately from Conrad, among others).

To drive three white LEDs in series a voltage of nearly 10 V is required to make sure that LEDs draw sufficient current. By powering the circuit from a 0.35 VA transformer only a limited amount of current is available, about 30 mA. This corresponds with the maximum value for the white LEDs that we used here (HLMP-CW24-TW000, 24⁹). So make sure you do not substitute a bigger transformer otherwise the current through the LEDs will be too high. More power is permitted only when the LEDs can handle that. But it is of course the intention that the circuit itself uses as little power as possible. In this way there is no need for a current limiting resistor. The 3 series connected LEDs actually function as a kind of zener diode, so the output voltage cannot drop below about 9.5 V (this depends on the exact forward voltage of the diodes, of course). In this way the power supply voltage for the opamp is always sufficient. The 78L08 regulator is mainly to limit the power supply voltage to the TLC272 and the regulator will stop regulating when a row of LEDs is fully illuminated. When none of the LEDs are turned on, the voltage across the filter capacitor C4 can increase to nearly 30 V

when a 15-V transformer is used (2 x 6 V can also be used, and incidentally, this type is also easier to obtain).

Construction and safety

The most obvious enclosure for this circuit is to build it into a case with integrated plug and socket. Unfortunately we were unable to find a transparent version. You can of course cut a hole in the enclosure and fit it with a window made from acrylic sheet of sufficient thickness.

Another idea is to buy a remote control switch that comes with a plug-and-socket enclosure and remove the electronics inside it. This is often cheaper than buying a separate case...

For safety considerations the LEDs may not protrude through the enclosure. The entire circuit is connected to the mains the LEDs are not specified for class-II isolation!

The remainder of the construction we leave to your own imagination.

(080415-1)

SHT11 Humidity Sensor Connected to PC

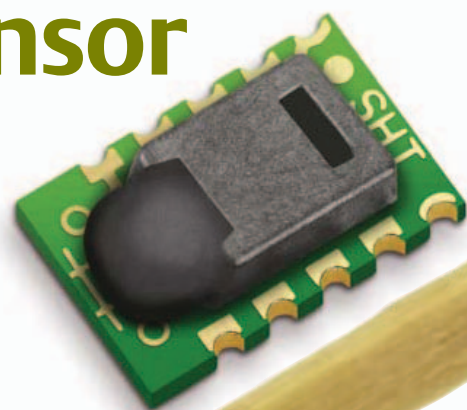
Trace and prove long-term % RH issues

The SHT11 humidity sensor made by Swiss company Sensirion measures both temperature and humidity in an all digital way. Here we investigate how it can be used to record and log air humidity over longer periods of time — with the help of a PC of course.

By Pavel Setnicar (Slovenia)

Although the datasheet of the SHT11 is essential reading [1] we can have a head start by mentioning that the device's output is pure digital; accuracy is $\pm 3\%$ RH and the measurement range is a solid 0–100% RH. For temperature, we have a range of -40 to $+125$ degrees Celsius (-40 to $+257$ degrees F). The SHT11's digital output closely resem-

bles I²C but in fact on closer inspection is different to the extent that certain protocol should be used to retrieve data. The sensor communicates with other devices through two pins called SCK and DATA. SCK (clock) is used for synchronizing with other device and the tri-state DATA pin transfers data to and from the sensor.



Certain start and command sequences are required to retrieve data from sensor and in good Swiss tradition these are well documented in the datasheet.

My goal was to connect this sensor to my PC, suitably programmed to take measurement at predetermined intervals, display sensor data on the screen and, if desired, save data as a text file on disk for analysis or documenting. The PC's legacy serial port (COM/RS232) was chosen for interfacing with the sensor because of its simplicity. Nowadays serial ports are rare on PCs, but there are USB to serial converters which do the job just fine.

The circuit diagram (Figure 1) of the little interface shows that the following signals are used on the serial port:

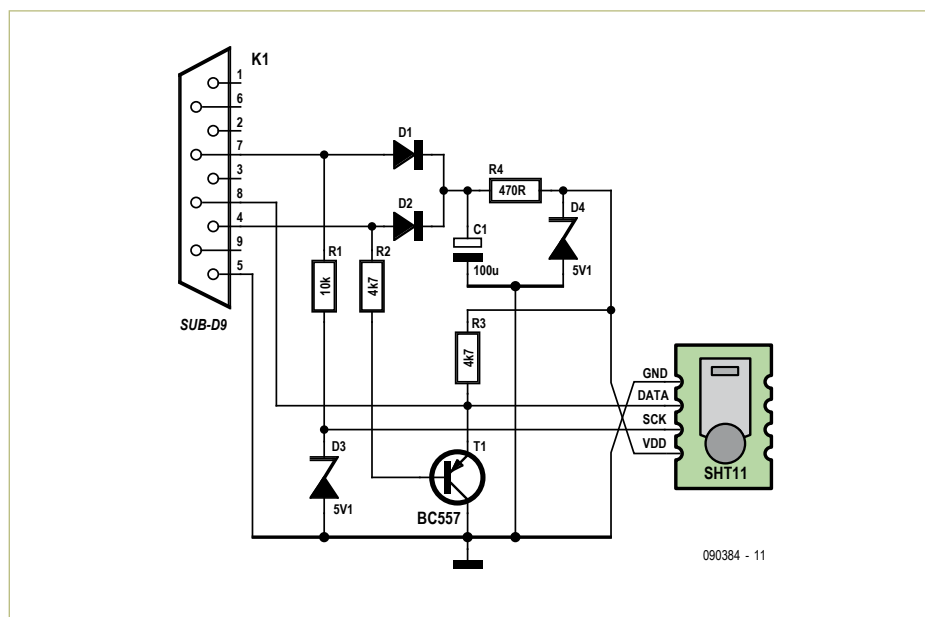


Figure 1. In terms of hardware this is all you need to connect the SHT11 sensor to a PC and do some serious temperature/humidity logging.

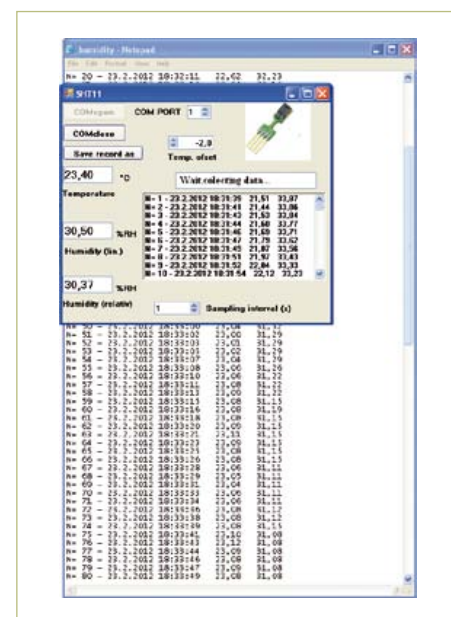


Figure 2. The program in action; data whooshing past but rest assured everything is logged securely for saving later.



- DTR (pin 4, Data Terminal Ready) to output data from the PC to the sensor via a BC557 tranny;
- RTS (pin 7, Request To Send) to clock the SHT11 as required for any transmission to and from the device;
- CTS (pin 8, Clear To Send), an input receiving data from the SHT11.

Power for the SHT11 is stolen (some say: borrowed) from the serial port signal pins. No problem since the current consumption of sensor amounts to a mere 0.5 mA when active. Moreover, the sensor is in idle state most of the time so average power is extremely low. The COM port signal pins are connected to two rectifying diodes D1 and D2 and capacitor C1 is charged through them. Depending on the computer used the voltage on the capacitor is roughly 10 V so it needs reducing to 5 V by zener diode D4.

Since the RS232 signals on the serial ports are typically ± 10 V, the clock signal also needs stepping down to 5 V by D3.

Using Bit Shifting-In and -Out (which is extensively documented in sensor datasheet) we get two chunks of raw information, one for temperature and one for humidity.

During my experiments I noticed a slight offset in temperature readings so I decided to extend the program with an option to calibrate the chip's temperature sensor. If for example readings for temperature are consistently 1.2 degrees Celsius too high you enter '-1.2' in the Temp.offset window.

Humidity data supplied by the sensor requires some math in terms of linearisation and this is done in program. For sticklers there an indicator window to see non-linearised values, and another for linearised values. The differences are very small because the non linearity of the sensor is minimal by all standards. In the lowest part of the screen a sample interval window is displayed, which allows you to set any desired period.

As shown in **Figure 2**, data is concatenated and scrolls past in the text window. If you want, you can save data on disk any time and work on it in other program (like Excel) at your convenience later. The control program was written in C# using Microsoft Visual Studio 2008. To install it on computer, Microsoft .NET framework 3.5 must be installed first. The free archive file at [2] includes the source code and program install package. The source code can be modified if desired provided you are familiar with C# and dot NET programming. The PC program was tested on several machines running Windows XP. It should also work with a USB to serial converter (like my STLab-4). The circuit was tested with a 5 m long cable (approx. 15 ft.) between it and the PC. An experiment is the only way to find out the maximum length.

(090384)

Internet Links

1. Sensirion SHT11 Datasheet:
www.sensirion.com/en/pdf/product_information/Datasheet-humidity-sensor-SHT1x.pdf
2. www.elektor.com/090384



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RAMBOard-Serial

Static RAM controller with SPI interface

By Markus Hirsch (Germany)

Even though performances of microcontrollers are improving as the requirements are getting more sophisticated, there are still many applications that use a small 8-bit processor. In some cases the actual processing capacity is not the main issue but the amount of memory needed. Enter RAMBO-S!

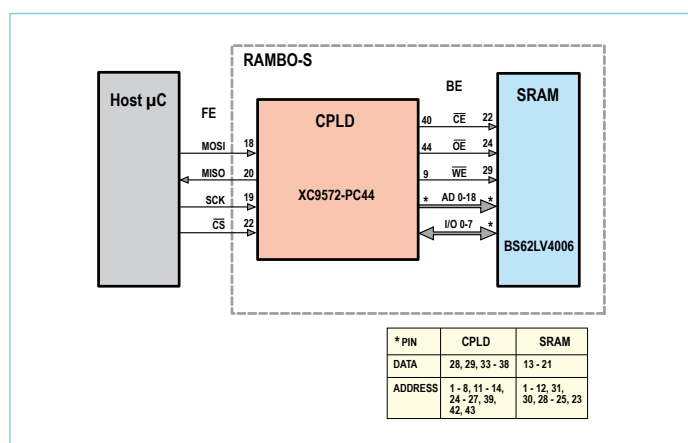


Figure 1. Sometimes a block diagram is virtually a circuit diagram.

The solution for this is either a bigger processor with the right amount of SRAM but also an overkill in performance or the use of an external memory together with the small processor. For lower

memory capacities there are solutions with a serial interface to spare address and data lines like the 23K256 SPI SRAM with 32 KB. But if larger amounts of memory are required like 512 KB or even more, you are faced with the problem that these SRAMs are only available as parallel addressable devices with ditto packages. With eight data bits and 19 or more address bits small CPUs quickly run out of I/O ports.

To solve the issue of a large amount of SRAM that can be accessed with a fast SPI interface, the solution is a controller that does all the addressing and parallel to serial shifting. For this purpose RAMBO-S got designed. In this design a Xilinx CPLD XC9572 in a PC44 case (44 pins, 34 user I/Os) was used to interface a 512 Kb SRAM IC like the BS62LV4006, although any standard SRAM with equivalent control lines can be used. To interface more SRAM ICs, a CPLD with more I/O lines would have to be used.

Hardware

Basically the circuit can be shown as consisting of only two components: the CPLD and the SRAM, see **Figure 1**. All the address lines

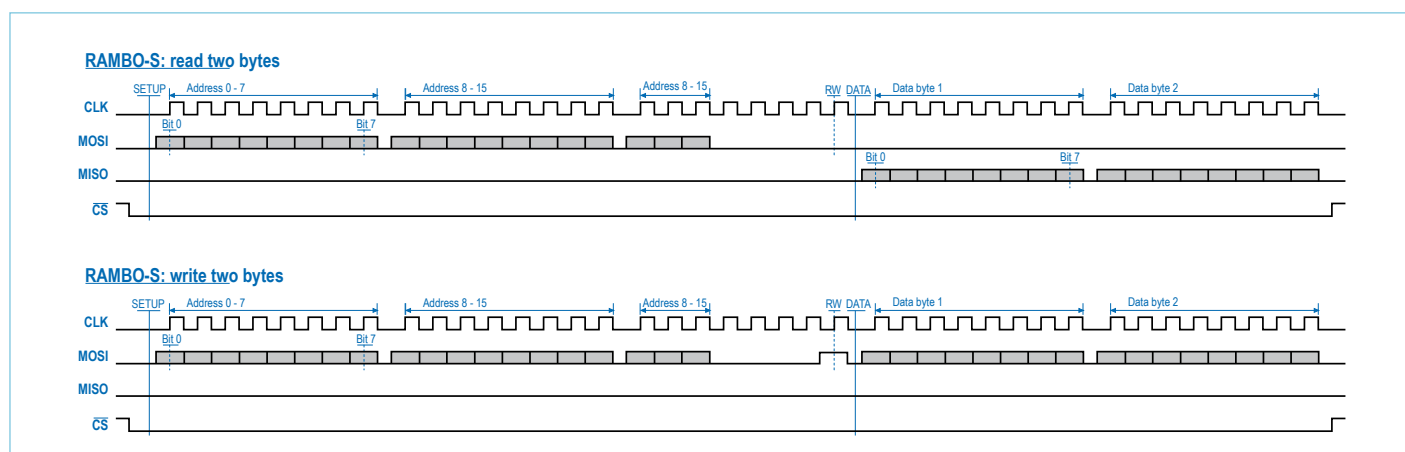


Figure 2. RAMBO-S read and write timing diagrams.

are wired directly to the CPLD without using a latch. Only a few decoupling capacitors should be used in addition.

The CPLD has a front end (FE) with SPI interface and a back end (BE) interface for the SRAM.

Interface

The firmware of the CPLD is designed such that no external components are needed. The clock line of the SPI interface is used to drive the internal logic. After shifting-in two address bytes and one setup byte (that holds three more address bits and the read or write select), the data bytes can be streamed in or out bitwise. The address is automatically incremented for each byte. **Figure 2** shows the pulse sequences for the read and write operations. The device was tested with a clock rate of 2.2 MHz. This would give a theoretical data rate of 275 KB/S. But the maximum achievable clock rate may well be higher.

Firmware operation

The firmware design files developed by the author are available for downloading from the article support page on the Elektor website [1]. These files should enable you to burn your own CPLD for the project, as well as get an understanding of what's going on in the device. Commercial use of the firmware files is not allowed. Referring to the labelled areas in the diagram in **Figure 3** the main parts of the firmware are (1) the SPI and input shift register, (2) the data input/output driver, (3) the output shift register, (4) the address counter phalanx, (5) the counter control logic and (6) the SRAM control logic.

When the \overline{CS} is High all the internal logic is reset and the device is in idle mode. As soon as the \overline{CS} goes low the three address setup bytes are required. The internal control logic loads the first 19 bits into the address counters and the last bit of the third byte sets the read/write logic.

Then the device goes in streaming mode. For each of the following bytes the address counters are incremented and the data is written or read from the SPI to the SRAM and vice versa.

The operation can be continued for any number of bytes and is terminated by setting \overline{CS} back High.

In order to address more than one SRAM the unused bits in the 3rd setup byte can be used with a decoder. For each IC one CE line is required.

(091090)

Internet Reference

1. www.elektor.com/091090

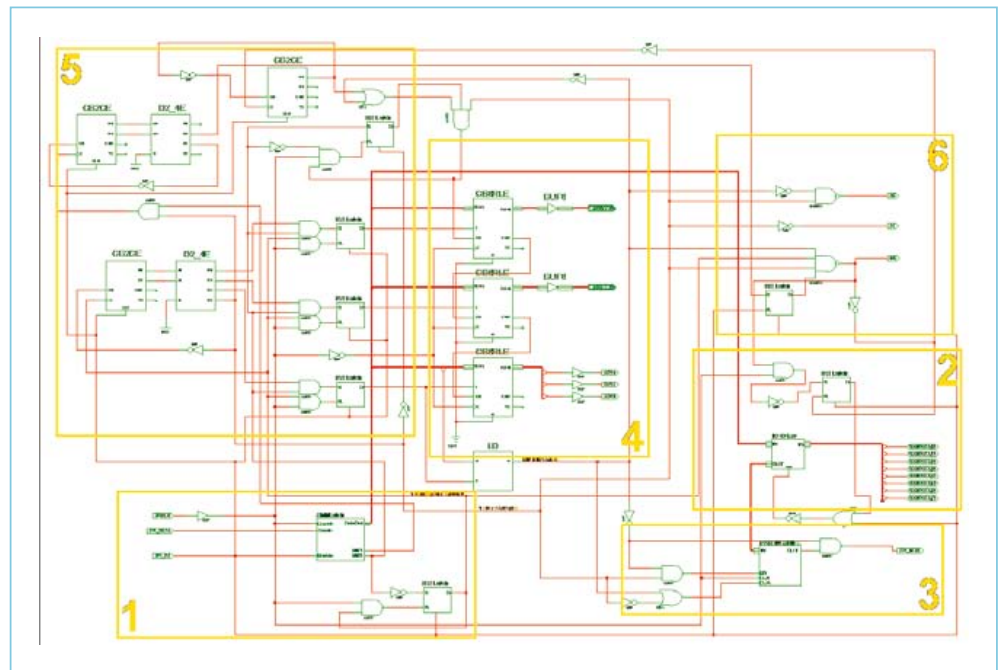


Figure 3. Details of the CPLD logic used in RAMBO-S.

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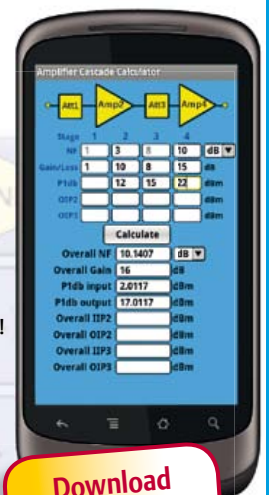
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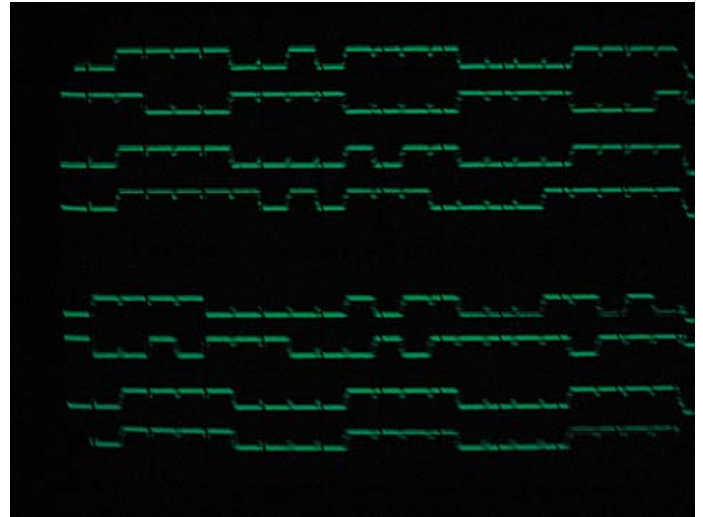
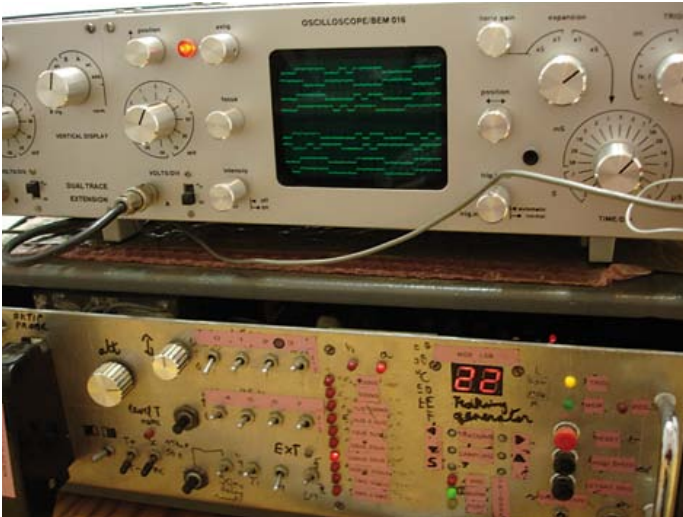
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Elektor Logic Analyser (1981)



By Luc Vanhove (Belgium)

Recently I dusted off my old logic analyser as part of a major house-cleaning exercise. The instrument dates from my time as a student in the 1980s. The only thing I didn't manage to do then was to make a nicely finished front panel for the analyser. Holding the instrument in my hands brought back lots of memories, and I was curious to see whether it still worked.

After collecting the associated cables, which by pure coincidence were still inside the unit, I connected them to a BEM016 oscilloscope (a MBLE kit project from the 1970s).

To my pleasant surprise, a waveform with eight steps in rising sequence appeared on the screen immediately, accompanied by random data at the top. After examining this for a bit I realised that an external trigger was needed, and there they were: all eight channels.

I built the Elektor design published in 1981 largely as described in the magazine, but with the circuitry fitted out with modern gadgets used in commercial instruments of that era. These circuits also appeared in Elektor, such as touch switches, a multiplexer for selecting the sampling clock rate, and a display for the selected clock rate. I also provided 12 V and ± 5 V on the probe to make experimenting easier. In addition, the probe was equipped with fast Schmitt trigger comparators to allow measurements to be made on CMOS ICs. I copied the vertical attenuator design from the storage scope to improve the accuracy. Of course, all of this made a more stable and heavier-duty power supply necessary, which required me to generate an entirely new design at that time.

The A/D converter board for this design has unfortunately gone missing, but I nevertheless would like to describe this relatively large project in more detail. It was published in five parts as follows:

- Logic Analyser part 1: Description - March 1981
- Logic Analyser part 2: Schematic diagram - April 1981
- Logic Analyser part 3: PCBs - May 1981
- Storage Scope - June 1981
- Logic Analyser Input Buffers - July & August 1981

Brief functional description

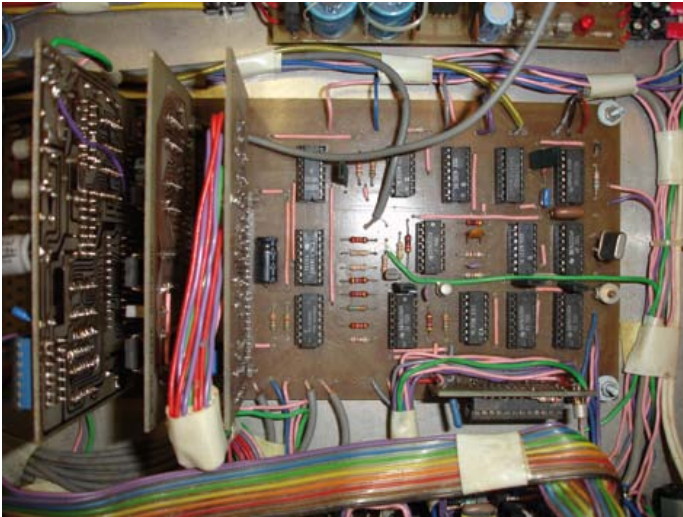
The input stage consists of an 8-bit latch (see **Figure 1**) with a fixed delay of 50 ns relative to the configured sampling clock or an adjustable delay of 150 to 500 ns. The signal at the input of the delay circuit comes from a 4-MHz crystal oscillator and clock divider to allow the desired sampling rate to be selected. In my version a multiplexer was used for this purpose instead of a selector switch. It is also possible to use an external clock, with the option of clocking on the rising edge or the falling edge of the clock signal.

The output from the frequency divider is connected to a presettable 8-bit counter (counter B), which counts from 0 in post-trigger mode, from 126 in centre trigger mode, or from 254 in pre-trigger mode. This counter determines the time when a Write Enable signal is sent to the memory.

The outputs from the 8-bit latch are connected to the inputs of the memory and to the XOR gates of the word recogniser, whose other inputs can be set to logic 1, logic 0 or 'don't care'. Flip-flop FF1 is set by the trigger signal from the word recogniser configured in this manner, or by either of two external trigger signals. It can also be set or reset manually.

Data is written to the memory after the trigger occurs. The counter counts the samples, and the process stops when the memory is full (after 256 samples). The memory addresses are provided by a second 8-bit counter (counter A), which is clocked at the set sampling rate.

After the memory is full, it is set to read mode by the Carry output of counter B, which drives flip-flop FF2. In this mode the counter reads out all of the memory locations at a fixed rate.

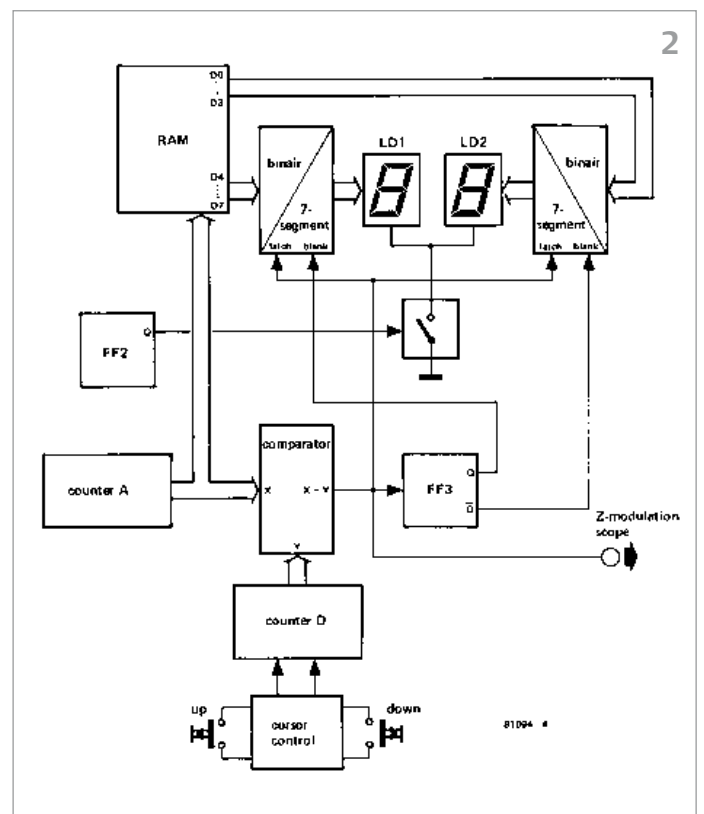
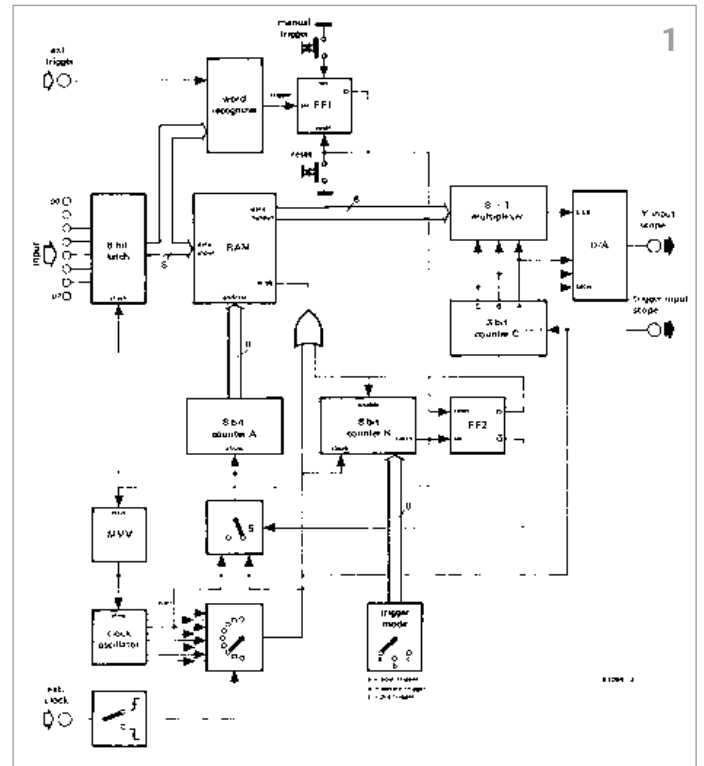


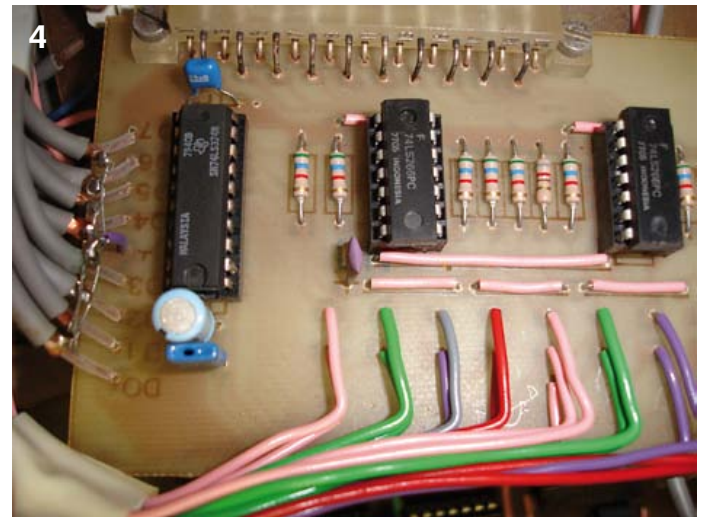
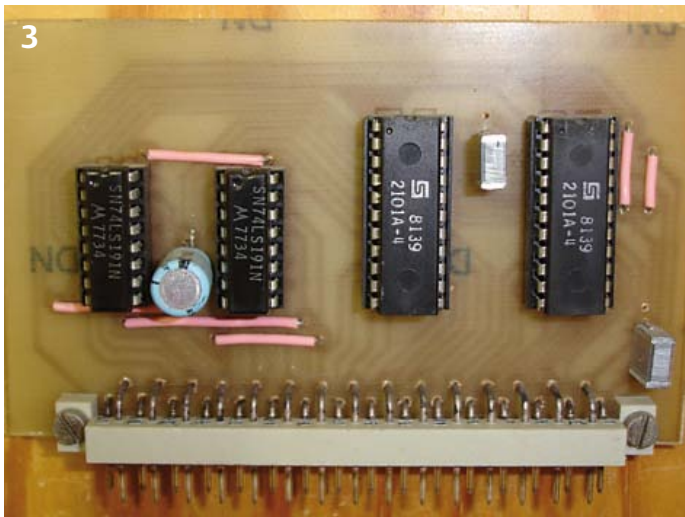
The data from the memory goes to an 8-to-1 multiplexer, which scans through all eight channels and adds a DC level to each bit stream via a D/A converter to simulate an eight-channel scope. This is a sort of visual sleight of hand because the analyser actually uses a single oscilloscope channel and an external trigger input. The external trigger is necessary to allow the eight channels obtained in this manner to be displayed and viewed synchronised with each other in vertical order.

There is also a separate branch from the memory data output, which is necessary for the cursor control circuit shown in **Figure 2** (where the memory, FF2 and counter A are the same as in Figure 1). The aim here is to select one bit from the eight data streams each time and display the data in hex notation. This is done by letting a counter count up or count down. The counter value is compared with the memory address by an XNOR circuit. A Z value pulse is generated when the two values match. This signal can be connected to the Z modulation input of the oscilloscope to cause the selected bits to be shown as bright spots. Some oscilloscopes do not have a Z modulation input, so the pulses are also superimposed on the output of the D/A converter, resulting in a bit signal with a descending pulse if the selected bit is a logic 1 or an ascending pulse if the selected bit is a logic 0. This makes it easy to recognise whether the bits are high or low in the case of bit streams with a constant value.

There is also another convenient way to read out hex values. For this purpose, the output signals from the memory are applied to the inputs of a BCD to 7-segment decoder. The decoder reads the input data into its register only when a Z modulation pulse appears via a flip-flop. The reset button for FF1 allows the write process to be set to the starting position, where it waits for the configured trigger value to occur.

Figures 3, 4, 5 and 6 show (respectively) the memory card, the input and trigger card, the cursor control card and the power supply for





the analyser. The hardware design is limited by the speed of the memory devices available at that time, which had an access time of 250 ns.

Storage scope

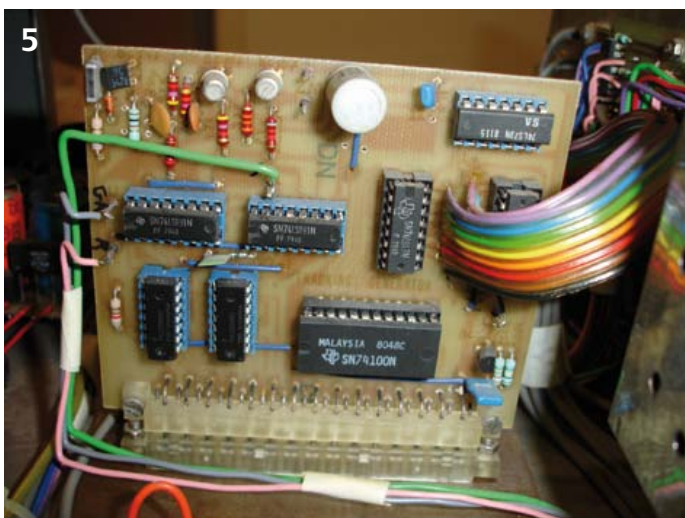
Given the logic analyser design, extending it to act as a digital storage scope was not especially difficult. All that was necessary was an additional module, equipped with an attenuator such as is used in a normal oscilloscope, that can amplify or attenuate the analogue signal and apply it to an A/D converter. The resulting digital data is stored in the memory. After the samples have been read in, read mode is activated and the output signals from the memory are applied to a D/A converter that reconstructs the analogue signal.

This function is very useful for non-repetitive signals, such as signals that occur with one-time events such as switching a circuit on or off, or signals that need to be monitored over a very long period. Logic analysers and digital storage scopes were unaffordable for hobbyists at that time, and the Elektor designs opened doors for troubleshooting and testing digital circuits.

Building a logic analyser with hardware alone is a fairly complex task. A beefy microcontroller and a few pages of software would have made the design a lot simpler, smaller and lighter, but in 1981 that was largely out of the question for enthusiasts.

The instrument is very stable in operation and sound in design. It never lets you down, even after 30 years.

(120219)



Hexadoku

Puzzle with an electronics touch

Pencil sharpened, eraser handy? No freerange family members yelling or offering consistently bad advice? Seated in the comfy chair? Good, all systems are GO for a new Hexadoku puzzle. Enter the right numbers in the puzzle below. Next, send the ones in the grey boxes to us and you automatically enter the prize draw for one of four Elektor Shop vouchers.

The instructions for this puzzle are straightforward. Fully geared to electronics fans and programmers, the Hexadoku puzzle employs the hexadecimal range 0 through F. In the diagram composed of 16×16 boxes, enter numbers such that **all** hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once only in each row, once

in each column and in each of the 4×4 boxes (marked by the thicker black lines). A number of clues are given in the puzzle and these determine the start situation. Correct entries received enter a draw for a main prize and three lesser prizes. All you need to do is send us the numbers in the grey boxes.

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Prize winners

The solution of the March 2012 Hexadoku is: 862DF.

The Elektor £80.00 voucher has been awarded to Ron Hodges (USA).

The Elektor £40.00 vouchers have been awarded to Eric Chamouard (France),

Esko Viiru (Finland) and Pascual Alagón Luna (Spain).

Congratulations everyone!

	7	8			E	F				A	4				B
9				0				8			7		4		6
5	B		1	3	6			F			D		0		A
	E						B					9	F		
		D					2			7	6				8
	8		3		4	6		5	9	C			7	D	
1		6	7			E	0	3		8					9
2					7	D				0					3
	F				2				7	4					E
E					8		3	1	6			B	5		F
	D	2		4	C		6		E	B		0		7	
3				E	F			D					A		
		B	D					2							F
7		E		6			1			F	5	8		4	0
4		A		F			E				9				D
8				2	0				1	D			6	5	

6	2	7	C	D	5	8	E	3	A	9	0	4	B	F	1
B	A	8	5	2	3	1	9	D	4	E	F	C	0	7	6
D	E	F	0	4	A	7	B	6	8	1	C	5	2	3	9
9	4	1	3	C	F	6	0	2	5	7	B	8	E	A	D
C	0	B	7	5	1	E	8	4	9	2	3	A	D	6	F
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5	9	A	6	7	C	2	D	E	F	8	1	3	4	B	0
F	B	9	A	8	4	C	1	0	3	6	7	D	5	E	2
7	1	E	8	6	2	D	F	C	B	5	A	0	9	4	3
0	5	2	D	9	7	A	3	1	E	F	4	B	6	C	8
3	6	C	4	0	E	B	5	8	2	D	9	7	F	1	A
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The competition is not open to employees of Elektor International Media, its business partners and/or associated publishing houses.

Reliability

By Gerard Fonte (USA)

Arguably, the biggest difference between a hobbyist-designed project and a commercial product is reliability. Hobbyists don't mind if they have to tinker with it from time to time. After all, we like to tinker. But you don't want to tinker every morning to get your car started, or with the toaster, or with your computer. A reliable product is tinker free.

Analyze This

It cannot be overstated that reliability comes from attention to detail. It's the small things that count. You need to take the time to examine all the aspects of any circuit the first time you design it. After the first time, you will know the important areas to look at. But for the first time, you have to consider every part.

My favorite example is the lowly unregulated, power supply. It's just a transformer, bridge rectifier and filter capacitor. Simple, right? If you choose a 24 volt transformer, then a 35 volt capacitor should be fine, shouldn't it? That's a 50% safety margin. The answer is a resounding, NO!

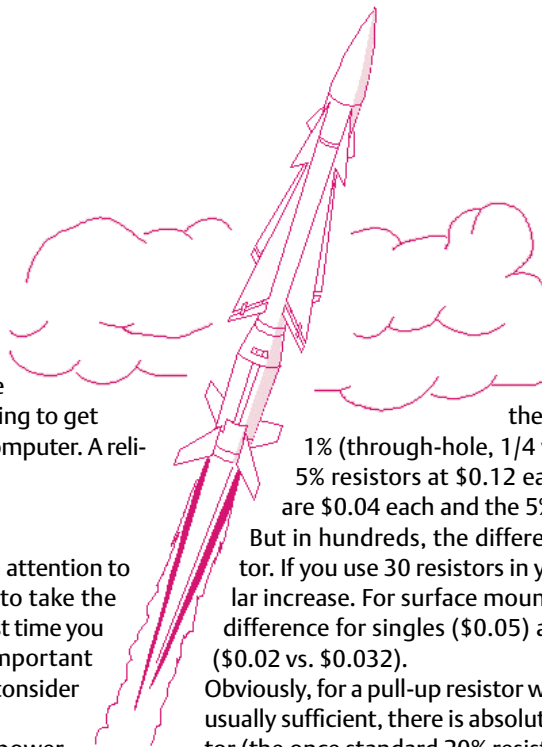
The transformer is rated in RMS voltage, under load; not peak voltage. The peak is 1.414 times the RMS or about 34 volts. Add about 10% for being unloaded and the actual DC voltage at the filter capacitor is over 37 volts. Capacitor confetti, anyone? And if you plan on using a common 3-terminal voltage regulator (LM78xx type) you should know that they have a maximum input of 35 volts (although there is some variation from manufacturer to manufacturer). Another failure in waiting.

You choose to use half-amp rectifiers because your design only draws 0.1 amps. To be extra safe you use a 2-amp transformer and high value capacitors you have on hand. There shouldn't be a problem here, should there? Yes there is. During turn-on the capacitors act as dead shorts across the transformer. During a short, the transformer's output is only limited by the resistance of the winding, which is typically about 0.5 ohms. In theory, a surge current of about 75 amps could occur (37 volts into 0.5 ohms). In practice it's quite complicated, but the usually accepted value (not guaranteed!) is 10 times the transformer rating. In this case, that's 20 amps (10 × 2 amps). Most silicon rectifiers are robust and can take very short surges up to 30 times their continuous rating or 15 amps here (30 × 0.5 amps). A surge of 20 amps into a 15-amp-surge rectifier won't go. Also, the length of the surge depends upon the size of the capacitors. The bigger the capacitors, the longer the surge. So, the reliability of the rectifier may depend more on the transformer and capacitor rather than the down-stream circuit.

It's important to see the critical need for proper circuit analysis for every part under every condition. You can't guess at reliability. You have to be sure.

More for Your Money

Hobbyists (like me) are perpetually short on cash. So, we tend to look for the minimum requirements for a part. Sometimes this isn't



the best choice. For example, why use a 1% resistor when a 5% resistor will work? The reason is that 1% resistors are so commonplace now that the price is virtually the same. My Mouser catalog shows

1% (through-hole, 1/4 watt) resistors at \$0.06 each and 5% resistors at \$0.12 each! In hundreds the 1% resistors are \$0.04 each and the 5% are \$0.01 each (more sensible).

But in hundreds, the difference is still only 3 cents per resistor. If you use 30 resistors in your design, that's less than a dollar increase. For surface mount resistors (1206 size) there is no difference for singles (\$0.05) and only about a penny for 100's (\$0.02 vs. \$0.032).

Obviously, for a pull-up resistor where any value from 1K to 100K is usually sufficient, there is absolutely no requirement for a 1% resistor (the once standard 20% resistors don't exist anymore). But for any application where a specific resistance is needed (voltage dividers, gain-setting, etc) the question is reversed. Why shouldn't you use a 1% resistor? Additionally, 1% resistors usually have better temperature stability.

It's a similar story for generic power rectifiers (1N400x). Different manufacturers have different basic prices for the diodes (I saw \$0.05 to \$0.15 each). But within the series (1N4001 to 1N4007) there was often no difference in price. The 1N4007 has a PIV (Peak Inverse Voltage) of 1000 volts where the 1N4001 has a PIV of only 50 volts. According to my Motorola Data Book, every other specification is the same. So, there is simply no reason not to buy the better diodes. You are getting much more for your money.

Look Before You Leap

These examples show the need to know what your design requires and what parts are available. Using parts that exceed the operational needs of the circuit will improve performance and reliability. And we've seen that this can be achieved with a minimum increase in cost or no increase at all.

The point is not to focus only on your needs when looking for parts. You might be able to find parts that are better than what you need for a small difference in price. And there are trade-offs. Which is more important in your design, the actual value of the capacitor or its working voltage? Will the lower on-resistance of the power MOSFET switch reduce heat build-up? Is it worth spending an extra dollar for a relay with 20 amp contacts versus 10 amp contacts? Does it make sense to use a solid-state relay, instead?

There is clearly much, much more to reliability than I can possibly cover here. There are many fine books on the subject. But fundamentally, designing reliable products is the result of a mind-set. It's not enough to make it work, it has to work well. And in order to do this, you have to consider every aspect of your design as well as the practical considerations of the parts that go into that design. After all (one of my favorites), engineering is just common sense with attention to detail.

(120236)

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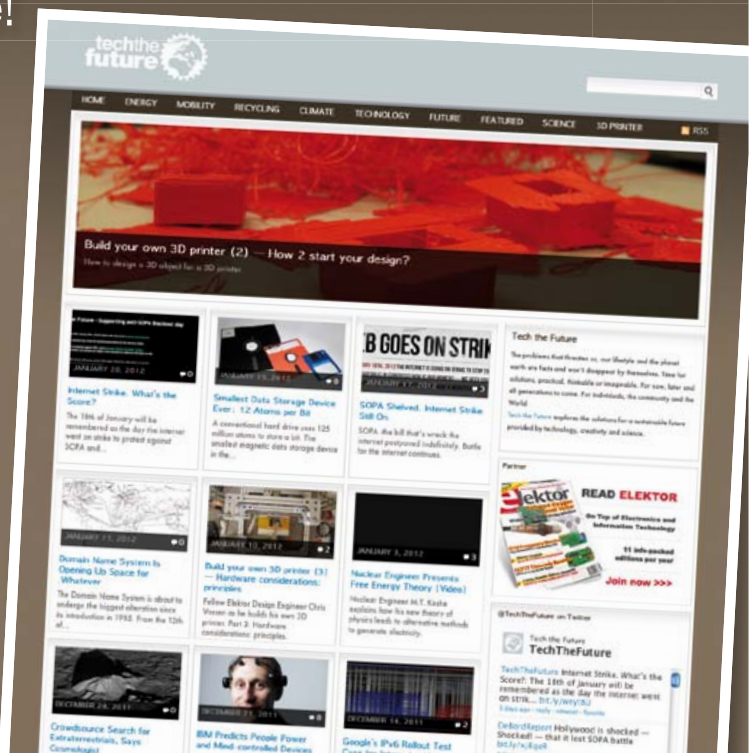
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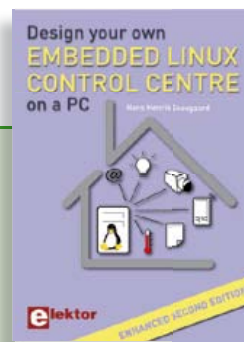


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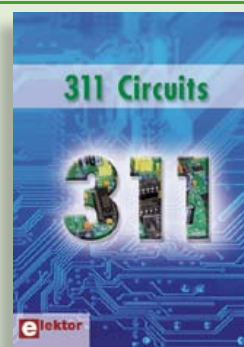


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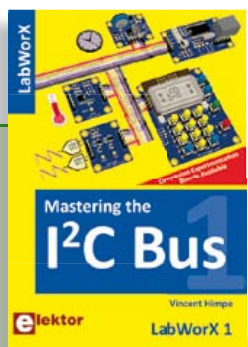


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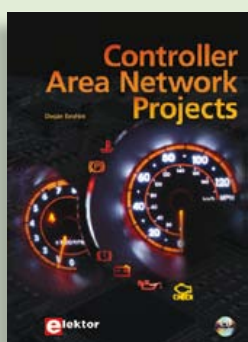


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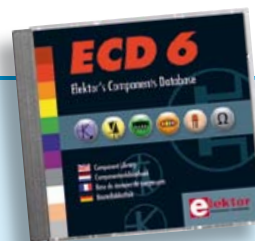
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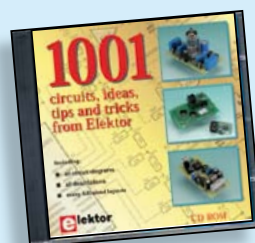


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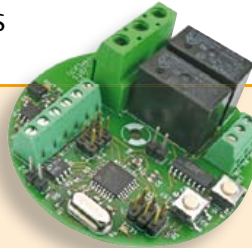
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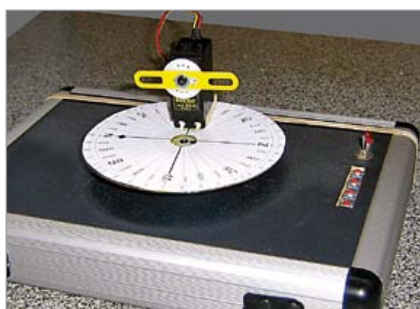
Nixie'd Thermometer / Hygrometer

Circuits with Nixie tubes rank tops everywhere, presumably because of the special attraction exerted by the magical glow of the lighted tube. In the June 2012 edition we present another design with four such tubes. This time we present a circuit that allows both temperature and humidity to be measured. In terms of hardware the project consists of a PIC microcontroller, a SHT21 air humidity sensor, a step-up converter built around a MC34063 and control of the Nixies with the good old 74141.



Swimmer's Distance Counter

It's a familiar sight in parks: the pedometer, a small device that counts the number of steps joggers have run. To our knowledge there's no such device for swimmers yet. Our design allows you to build an 'aquameter' (if that is the correct name), which counts the swimmer's number of head movements. The circuit is simple and mainly consists of a microcontroller and a readily available accelerometer module.



Heliostat

A heliostat is a device for tracking moving objects in the sky. This way you are able to maintain a maximum amount of sunlight to absorb on a surface, take a series of photographs of a moving planet or detect a satellite for optimal reception using a dish. This project in the June 2012 edition describes the outlines of a heliostat made from two servo motors. With the aid of a model continuously calculating the sun's position as a function of the time and place on earth, the servos are driven and always pointed in the direction of the sun.

Article titles and magazine contents subject to change; please check the Magazine tab on www.elektor.com

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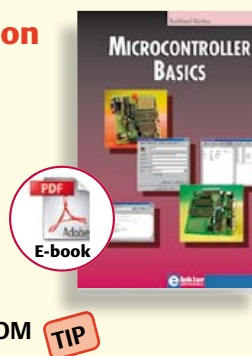


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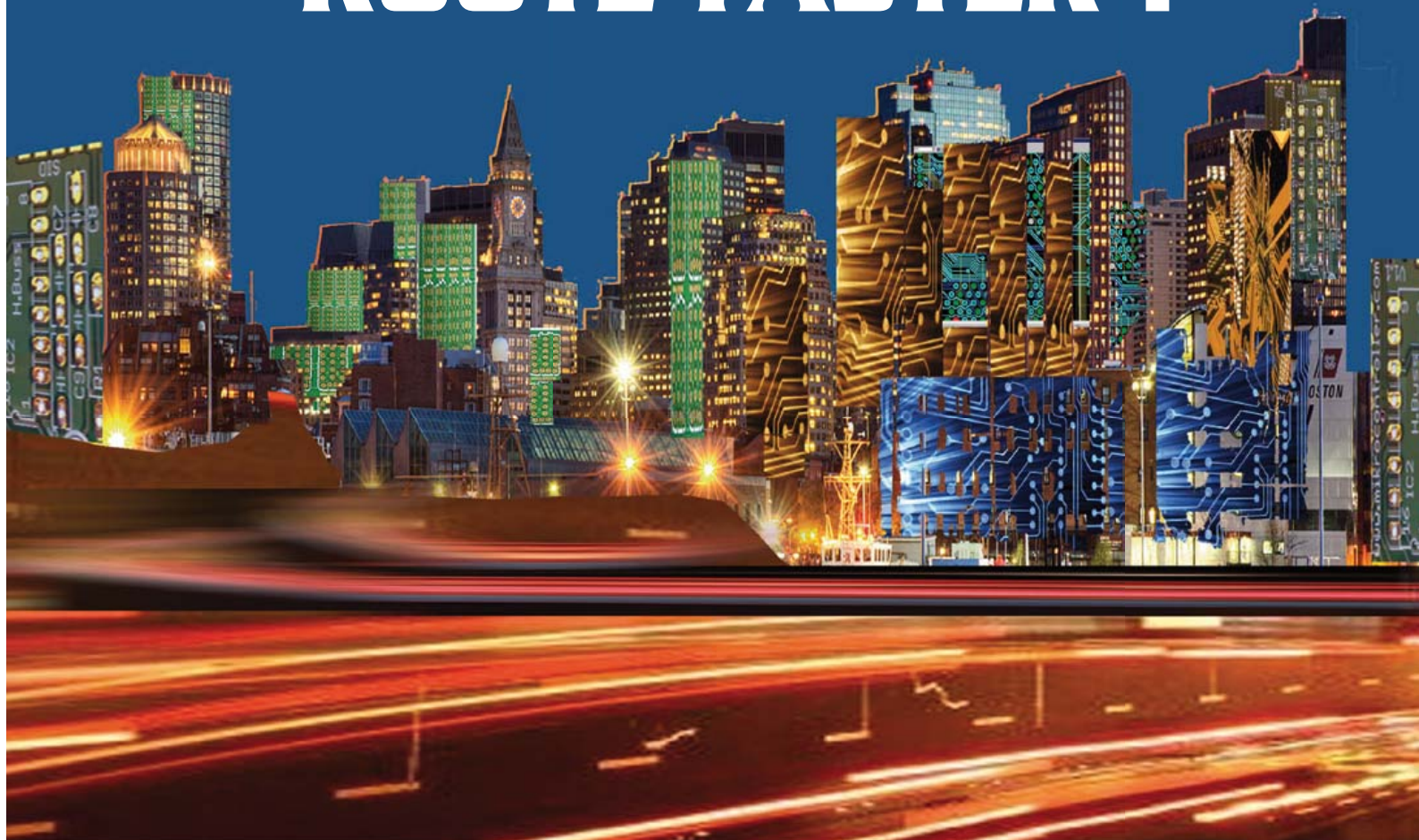
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